March 1986
Vol. 49, No. 4

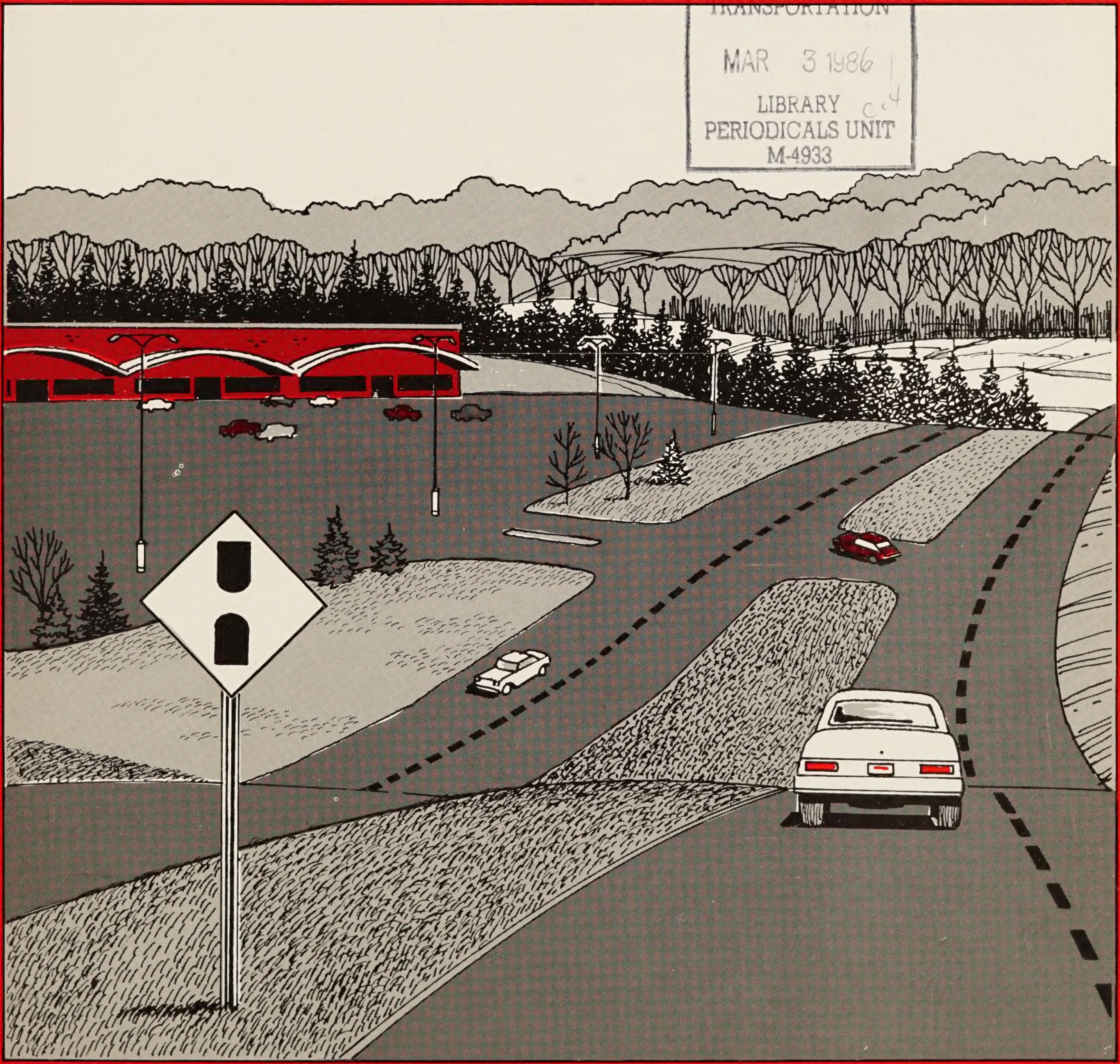
Public Roads

U.S. Department of Transportation

Federal Highway Administration

A Journal of Highway Research and Development

DEPARTMENT OF TRANSPORTATION
MAR 3 1986
LIBRARY
PERIODICALS UNIT
M-4933



Public Roads

A Journal of Highway Research and Development

March 1986
Vol. 49, No. 4

U.S. Department of Transportation
Elizabeth Hanford Dole, *Secretary*

Federal Highway Administration
R.A. Barnhart, *Administrator*

U.S. Department of Transportation
Federal Highway Administration
Washington, DC 20590

COVER: An advanced warning median crossover symbolic sign showing two median crossover noses did well in legibility and understanding tests, was least confused with other signs tested, and was most preferred by subjects in a study conducted at the Turner-Fairbank Highway Research Center in McLean, Virginia.

IN THIS ISSUE

Articles

Departments

Public Roads is published quarterly by the Offices of Research, Development, and Technology
David K. Phillips, *Associate Administrator*

Technical Editor
C.F. Scheffey

Editorial Staff
Cynthia C. Ebert
Carol H. Wadsworth
William Zaccagnino

Advisory Board
R.J. Betsold, S.R. Byington, R.E. Hay, George Shrieves

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of an article.

Address changes (send both old and new) and requests for removal for the free mailing list should be directed to:
Public Roads Magazine, HRD-10
Federal Highway Administration
6300 Georgetown Pike
McLean, VA 22101-2296

At present, there are no vacancies on the *FREE* mailing list.

Public Roads, A Journal of Highway Research and Development, (ISSN 0033-3735) is sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, for $12 per year ($3 additional for foreign mailing) or $3.25 per single copy (81¢ additional for foreign mailing). Subscriptions are available for 1-year periods. Free distribution is limited to public officials actually engaged in planning and constructing highways and to instructors of highway engineering. At present, there are no vacancies on the free mailing list.

The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department.

Contents of this publication may be reprinted. Mention of source is requested.

DEPARTMENT OF
TRANSPORTATION
MAR 3 1986
LIBRARY c.4
PERIODICALS UNIT
M-4933

Investigation of Warning Signs for Median Crossovers

by

Gillian M. Worsey, Charles E. Dare,
Richard N. Schwab, and Samuel C. Tignor

This article describes the results of a study of advanced warning median crossover signs that were tested in a laboratory for legibility, understanding, recognition, and preference. The study indicated that the most appropriate word message sign would be MEDIAN CROSSOVER. Such a sign was not actually tested but the subjects understood a MEDIAN OPENING sign the best, and the majority of subjects thought that "crossover" was the word that best conveyed the intended meaning. Legibility of the symbolic signs, however, was much greater than for the word messages.

The symbolic sign found to be the best out of those tested was one showing two crossover noses. This sign did well in legibility and understanding tests, was least often confused with other signs, was the sign most preferred by the subjects, and also was the simplest of the warning sign symbolic designs.

Introduction

Median openings often are used on divided arterials and other nonfreeway highways between intersections to accommodate minor turning movements into driveways and U-turns to assist maintenance operations, policing, and repair service to stalled vehicles. About 35 percent of the accidents occurring between intersections on four-lane highways involve median openings. (*1*)[1] The largest percentage of these accidents involves vehicles attempting to cross four lanes through a median opening (table 1).

The Manual on Uniform Traffic Control Devices (MUTCD) provides for the use of a median crossover sign (D13-1) but does not suggest nor identify an advanced, warning-type traffic control device for median crossovers. Roadway delineators used to identify horizontal alignment and hazards adjacent to the roadway are also commonly used at median crossovers.

In response to a proposal by the Virginia Highway and Transportation Research Council (VHTRC) that a research study investigate the effectiveness of traffic control devices at median crossovers, the Federal Highway Administration (FHWA) conducted such a study last summer at its Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia. This article describes the investigation of the effectiveness of various advanced warning signs and delineators at median openings.

Study Methodology

Test Signs

Sixteen candidate advance warning median crossover signs were identified from a literature review and survey of current State practices. To keep testing time to approximately 1 hour, only seven of these signs were selected for laboratory testing of legibility, understanding, and driver recognition.

[1]Italic numbers in parentheses identify references on page 121.

Table 1.—Frequency of median opening accidents by accident type (*1*)

Accident type	Accidents Number	Percent
Hit while attempting to cross four lanes	899	39
Hit from front while turning through median opening	589	25
Hit from rear while turning from outside lane	445	19
Hit from rear while turning through median opening	297	13
Hit from rear after turning through median opening	88	4

The seven candidate signs included five symbolic and two word signs (fig. 1). The word sign CROSSOVER was used because it is the wording on the sign included in the MUTCD, and the word sign MEDIAN OPENING was used because it included the word "median."

Five of the signs tested were yellow diamond warning signs. The two permissive signs included the sign from Virginia that led to the original study request and a Permissive U-Turn sign, both of which had green backgrounds to denote permissive signs.

The seven signs were composed on a computer graphics system as were three other signs used as distractors. Ten other MUTCD signs composed on the computer graphics system as part of other FHWA studies also were used as distractors, making a total of 20 signs for subject viewing. The signs were superimposed onto a digitized photograph of a median crossover so that the crossover signs were in an appropriate environment with associated visual cues. Slides and prints then were made of the superimposed signs (fig. 2).

The slides were rear-projected onto a translucent screen. The size of the projected image of the signs, 2 3/8 in (60.3 mm) from point to point of the yellow diamond, was chosen so that subjects with the best eyesight could not recognize familiar signs at the farthest distances from the image (110 ft [33.5 m]). A long advance projector control cord allowed the slides to be advanced from the 110-ft (33.5-m) distance.

The testing took place in a tunnel approximately 12 ft (3.7 m) wide by 12 ft (3.7 m) high by 120 ft (36.6 m) long at the TFHRC. The slide projector and screen were at one end of the tunnel.

Subjects

Thirty paid subjects participated in the testing—five males and five females from each of three age groups (16-29 years, 30-49 years, and 50 years and over). The mean age was 40.5 years (table 2). All subjects had their vision tested to ensure corrected visual acuity of 20/33 or better. The average visual acuity was 20/20. The 16 subjects who wore corrective lenses for driving also wore them during the laboratory testing. All subjects had correct color vision.

Testing procedure

The study addressed the subjects' understanding and recognition of the signs tested as well as the legibility of the signs. Legibility, or the clarity of the sign, involves letter size, width, and spacing; color; and contrast. Understanding relates to the subject's ability to correctly interpret the meaning of the sign. In this study, the initial measure was the subject's uncued understanding; before seeing the seven candidate signs, the subjects were not given any information on the meaning or purpose of the signs. After the subjects had been initially tested with all of the candidate signs, the signs' meanings were explained. This subsequent sign understanding in further testing was known as cued understanding. Recognition relates to the subject's cued understanding and ability to identify a sign correctly in a short period of time.

Legibility and understanding

Each subject was briefed on how the testing would be conducted. After any questions the subject had were answered, the first slide was projected on the screen. The subject walked toward the projected sign until he/she could identify any feature on the sign. The feature and the distance at which it was identified were recorded until all the major features of each sign had been identified.

The subjects also were instructed to give the uncued meaning of the sign as soon as they thought they knew it. If the meaning they gave was incorrect, they were instructed to try again. To prevent long viewing times, the subjects were encouraged to guess, if necessary, the meaning of the sign.

When the subject had identified all of the features of the sign, he/she walked back to the beginning of the tunnel, the next slide was presented, and the procedure was repeated. This process was repeated until the subject had seen all 20 slides. The slides were presented randomly (a different order for each subject) with the stipulation that the first two signs were not candidate crossover signs. In this way, the subjects, without being aware of it, practiced the procedure with a distractor sign.

Recognition

After the subjects had completed the sign legibility and understanding testing, the intended meaning of the crossover signs was explained and the subjects were given prints of the seven candidate median crossover signs to become familiar with them.

Table 2.—Mean ages of subject groups

Sex	Age in years 16–29	30–49	50 and over	Mean
Male	21.2	38.8	59.8	39.93
Female	24.0	42.0	57.4	41.13
Mean	22.6	40.4	58.6	40.50

CROSSOVER
(black on yellow)

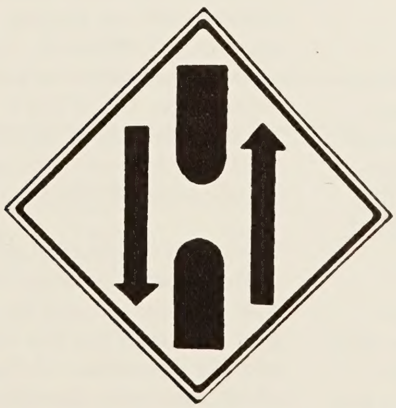
Crossover Arrows
(black on yellow)

Permissive Crossover—Virginia
(white on green)

MEDIAN OPENING
(black on yellow)

Permissive U-Turn (black on white, green background)

Crossover Nose
(black on yellow)



Crossover Nose plus Arrows
(black on yellow)

Figure 1.—Candidate median crossover signs.

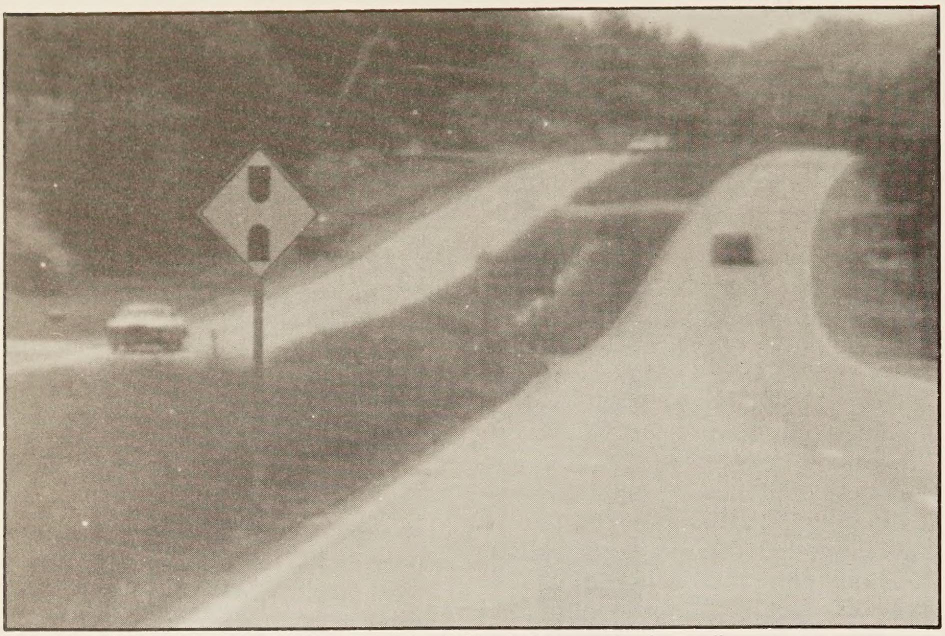


Figure 2.—Crossover sign superimposed onto digitized photograph of a median crossover.

The subjects were shown the slides again, this time in a different random order. The subject walked toward the projected sign until he/she could identify it. Again to prevent long viewing times and to maximize confusion, the subjects were encouraged to guess the signs' meanings as far as possible from the screen. Any confusion and the distance at which it occurred were recorded as was the distance at which the subject correctly identified each sign. When each sign had been identified correctly, the subject walked back to the beginning of the tunnel, the next slide was presented, and the procedure was repeated until each subject had seen all 20 slides.

Preference

Although the three basic study areas were legibility, understanding, and recognition, a fourth area of interest was subject preference for the candidate signs. In the final part of the testing, the subjects were instructed to arrange prints of the seven crossover signs in order of preference. The rank of each sign then was recorded. The subjects also were asked several questions concerning their thoughts on the use and meaning of median crossover signs.

Results

Legibility

Table 3 summarizes statistics for the identification of features data. The mean distances reported here in feet are a relative measure of legibility from this laboratory test and not the distances at which drivers would be able to read the signs in a real driving situation.

Sign shape was identified for all but the Virginia sign at a mean of approximately 100 ft (30.5 m). The shape of the Virginia sign could not be identified until considerably closer—a mean of approximately 63 ft (19.2 m). Statistical analysis showed mean distance for the Virginia sign was significantly different. Sign color could be identified at a mean of approximately 100 ft (30.5 m) or more for all of the signs, and the mean distances for each sign were not significantly different.

The mean distance at which the color of the symbol or letters could be seen was between 70 and 90 ft (21.3 and 27.4 m) for all but the Virginia sign and the Permissive U-Turn sign, which had color identification distances of approximately 57 and 55 ft (17.4 and 16.8 m), respectively. Statistical analysis showed these two mean distances were significantly different.

The presence of a symbol could be seen at a mean of approximately 80 to 90 ft (24.4 to 27.4 m) for the Crossover Nose, Crossover Nose plus Arrows, and Crossover Arrows signs; for the Permissive U-Turn sign and the Virginia sign, the means were shorter, approximately 66 and 52 ft (20.1 and 15.8 m), respectively. Letters on word signs could not be seen until somewhat closer—a mean of approximately 54 ft (16.5 m) for the MEDIAN OPENING sign and a mean of approximately 48 ft (14.6 m) for the CROSSOVER sign. Statistical analysis again showed that these mean distances were significantly different.

The individual pictographic elements on each sign were identified at varying distances; the most obvious result was that the word signs could be read only at very short distances—a mean of approximately 12 ft (3.7 m) for the CROSSOVER sign and a mean of approximately 11 ft (3.4 m) for the MEDIAN OPENING sign. Statistical analysis of the distances at which the smallest pictographic element could be identified showed that these mean distances were significantly different.

The directional information conveyed by the symbol on the Crossover Arrows sign could be seen at a mean of approximately 50 ft (15.2 m) compared with a mean of approximately 35 ft (10.7 m) for the presence of the crossover nose symbol on the Crossover Nose, Crossover Nose plus Arrows, and Virginia signs. The symbol on the Permissive U-Turn sign was seen the least well, at a mean of approximately 25 ft (7.6 m).

No significant relationship was found between the identification distance and the size of the largest dimension of the symbol or the largest dimension of individual pictographic elements. No significant relationships were found between identification distances and biographic variables such as age, sex, weekly mileage driven, accidents and violations in the past 5 years, and wearing corrective lenses. As might be expected, subjects with the best visual acuity had longer identification distances for all of the signs but the Permissive U-Turn sign.

Table 3.—Means and standard deviations of legibility distances (ft)

Feature		Sign: CROSSOVER	MEDIAN OPENING	Permissive Crossover—Virginia	Crossover Nose	Crossover Nose plus Arrows	Crossover Arrows	Permissive U-Turn
Shape of sign	M	99.90	106.67	62.77	101.96	103.63	108.20	100.64
	SD	15.35	10.18	29.38	12.91	12.50	5.64	19.73
	N[1]	30	30	26	28	30	30	28
Color of sign	M	106.30	107.87	99.03	105.67	107.40	107.80	100.27
	SD	7.47	7.01	20.85	9.91	6.99	5.93	19.75
	N	30	30	30	30	30	30	30
Color of symbol or letters	M	74.96	70.95	57.48	78.82	84.04	89.16	54.92
	SD	26.29	25.20	27.54	24.84	22.15	22.09	31.58
	N	23	22	29	28	27	25	26
Presence of symbol or letters	M	48.10	53.93	51.75	82.54	84.86	89.56	65.88
	SD	24.59	19.42	20.24	21.53	21.65	20.97	28.22
	N	29	30	8	26	29	25	25
Presence of median nose	M			34.03	36.20	34.60		26.43
	SD			12.61	10.88	13.42		11.98
	N			30	30	30		30
Road pattern	M					34.43	52.23	24.97
	SD					11.71	16.59	6.69
	N					30	30	30
Crossover movement	M						48.37	24.73
	SD						11.77	7.08
	N						30	30
Read legend	M	12.27	11.40					
	SD	3.50	3.41					
	N	30	30					

[1] Sample sizes (N) differ because not all subjects mentioned all features.

1 ft = 0.305 m

Legend
M = Mean
SD = Standard deviation
N = Number of subjects

A breakdown of the data according to sex showed that the females identified the shapes and colors of the signs and the presence and colors of the symbols at slightly longer distances, whereas the males identified the details on the signs at longer distances. However, statistical analysis did not show any significant effects of sex on the legibility distances. A breakdown of the data according to age did not show any consistent differences.

Uncued understanding

The subjects were encouraged to guess the meaning of the signs as soon as possible. Their answers were coded according to whether they made an incorrect guess before a correct one or could not guess the meaning (table 4). No consistent patterns of replies were found when the data were broken down according to age or sex.

The sign that conveyed the meaning most successfully was the MEDIAN OPENING sign for which all of the subjects gave the correct meaning, 27 of the subjects without a wrong guess first. Least understandable was the Permissive U-Turn sign for which only 15 subjects gave the correct meaning and only 9 of these subjects

Table 4.—Frequencies of correctness of answer by kind of sign

Kind of answer	Sign: CROSSOVER	MEDIAN OPENING	Permissive Crossover—Virginia	Crossover Nose	Crossover Nose plus Arrows	Crossover Arrows	Permissive U-Turn
Correct answer first time	16	27	13	18	15	13	9
Partially correct answer before correct answer or Incorrect guess before correct answer	10	3	4	5	8	11	6
Incorrect guess and no correct answer or Don't know	4	0	13	7	7	6	15

without a wrong guess first. The Virginia sign also caused problems, with 17 subjects giving a wrong guess first, and 13 of these subjects never guessing the correct meaning.

The signs were confused or misinterpreted nearly 100 times (table 5). The Crossover Arrows sign was confused most often, mainly with "hospital" or "H." The Crossover Nose plus Arrows sign also was confused numerous times, mainly with "divided highway" or "two-way traffic." The CROSSOVER sign was confused an equal number of times, mainly with "crossroads," "bridge or overpass," and "construction." Confusion of this word sign occurred probably from misreading rather than from not understanding the meaning of the sign. Some of the more obscure misinterpretations of the signs included "mountains," "football," "tunnel," "jogging," and "use seatbelts."

Table 6 shows the frequency of misinterpretations based on age and sex. The 30-49 years age group misinterpreted the signs more often than did the other age groups. Females 16-29 years old misinterpreted the signs more often than did males of the same age group, but this could be because of a greater willingness to guess rather than because of a greater difficulty in understanding the signs. No pattern was found in the kinds of misinterpretations for each sign according to age or sex.

The mean distances at which subjects understood the meanings of the signs are shown in figure 3. The word signs were understood at much shorter distances than the symbolic signs because the subjects had to be able to read the signs before they could understand them. The Crossover Arrows sign was understood at the farthest distance and also by the most subjects; however, this sign also caused the most confusion before a correct answer was given. Statistical analysis of the distances at which subjects understood the signs showed that the distances were significantly different.

No significant relationships were found between understanding distances and biographic variables such as age, sex, weekly mileage driven, accidents and violations in the past 5 years, visual acuity, and wearing corrective lenses. A breakdown of the data according to age and sex did not show any consistent differences.

Recognition

The recognition tests were conducted after the subjects were told the meaning of the signs. Figure 4 shows the mean distances at which the subjects recognized the signs. The Virginia sign was recognized at by far the greatest mean distance because of its distinctive color and shape, followed by the Permissive U-Turn sign. The word signs again were recognized at the closest mean distances. Statistical analysis of the mean recognition distances showed that the distances were significantly different.

Table 7 shows the frequency of confusions for each sign. The Crossover Nose sign was the only sign not recognized by all of the subjects. The total number of confusions was only 20; 8 of these involved the Crossover Nose plus Arrows sign, which mainly was confused with "divided highway." The Crossover Arrows sign was confused five times.

No significant relationships were found between recognition distances and biographic variables such as sex, weekly mileage driven, accidents and violations in the past 5 years, and wearing corrective lenses. However, age was negatively related to recognition distances for the MEDIAN OPENING, Crossover Nose, Crossover Nose plus Arrows, and Crossover Arrows signs; younger subjects found these signs easier to recognize than did older subjects. The recognition distances for younger subjects also were longer than for older subjects for all of the symbolic signs but not for the word signs. Mean recognition distances were longer for each younger age group; however, statistical analysis did not show any significant effects of age on the recognition distances.

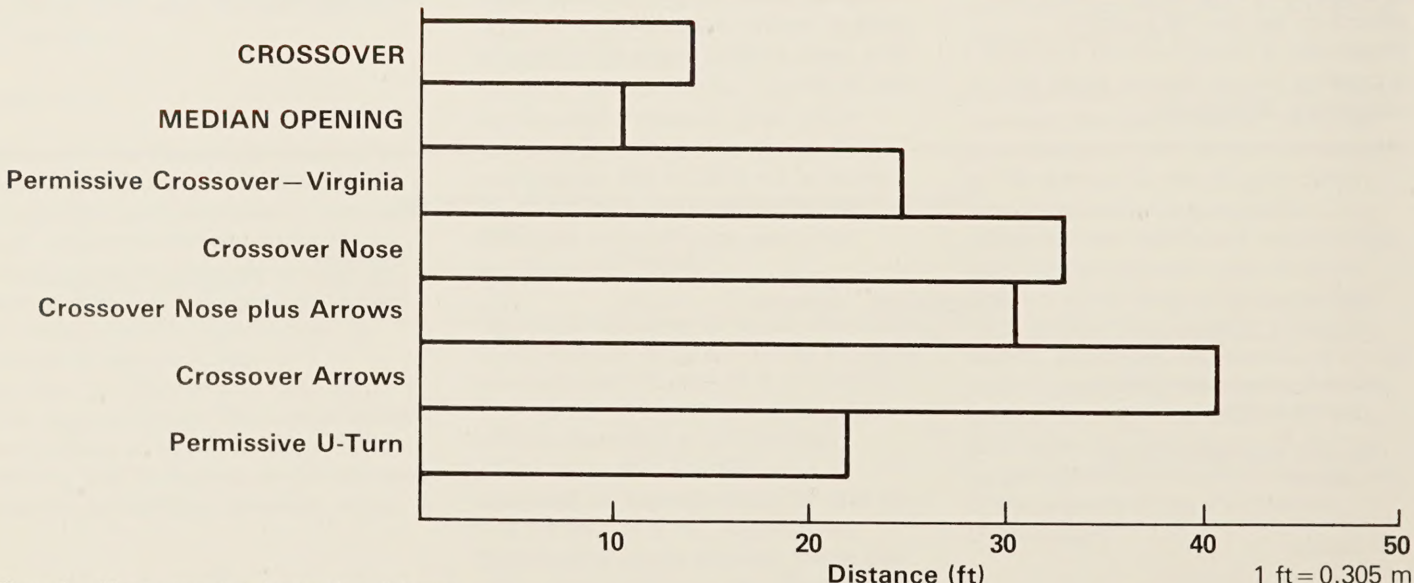


Figure 3.—Mean uncued understanding distances.

Table 5.—Frequencies of misinterpretations by kind of sign

	Sign						
	CROSSOVER	MEDIAN OPENING	Permissive Crossover—Virginia	Crossover Nose	Crossover Nose plus Arrows	Crossover Arrows	Permissive U-Turn
Misinterpretations	18	5	10	11	18	23	13
Subjects who could not guess the meaning at all	0	0	8	3	2	0	10

Table 6.—Frequencies of misinterpretations by age and sex

Sex	Age in years 16–29	30–49	50 and over	Total
Male	11	21	14	46
Female	19	19	14	52
Total	30	40	28	98

A breakdown of the data according to sex did not show any consistent differences in the mean recognition distances; however, females confused the signs with other meanings more often than did males.

Preference

Figure 5 shows the mean preference ranking subjects gave to the signs. They ranked the sign that they thought best conveyed the message of a median crossover as number 1 and the sign that they thought least conveyed the message as number 7. The most obvious conclusion from figure 5 is that the Permissive U-Turn sign was the least preferred, with an average rank of 6. The Crossover Nose and Crossover Nose plus Arrows signs were the most preferred, followed by the two word signs, the Crossover Arrows sign, and the Virginia sign. Statistical analysis indicated there was a significant difference among the mean preference ranks of the signs. A breakdown of the preference rank data according to age and sex showed the most agreement within the 16–29 year age group in ranking the signs, especially among the females.

Subjects' answers to general questions on median crossovers indicate a need exists that could be filled by the use of crossover signs. Twenty-two of the subjects (73 percent) thought public use of crossovers constitutes a hazard on divided highways, and 29 subjects (97 percent) thought that a sign would help them locate a crossover.

Subjects clearly were aware of the problems associated with crossovers. The most frequently mentioned hazard was slowing traffic in the fast lane, followed by traffic accelerating into the fast lane, turning traffic, and lane changes. One subject thought a crossover might lead to someone driving on the wrong side of the road. The possibility of rear-end collisions was mentioned by seven subjects, and broadside collisions by four subjects. Only two subjects did not associate any hazard with crossovers.

Subjects also were asked what effect a crossover sign would have on their driving. Twelve subjects said they would look for the sign if they wanted to locate a crossover, and two subjects said they would be able to change lanes or to signal when they saw the sign if they wanted to use a crossover. Fifteen of the subjects said they would look for slowing traffic if they saw a crossover sign, five said they would slow down, and four said they would change lanes. Only one subject said the sign would have no effect on his/her driving.

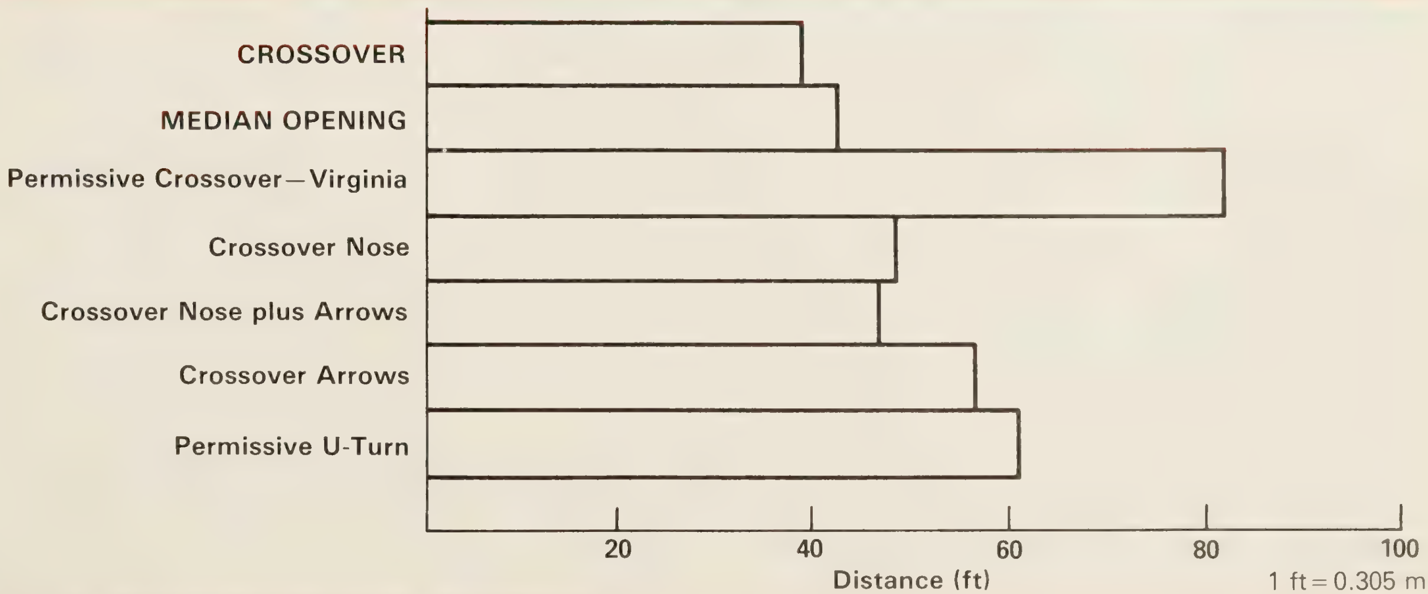


Figure 4.—Mean recognition distances after cued understanding.

Table 7.—Frequencies of confusions by kind of sign after cued understanding

	Sign						
	CROSSOVER	MEDIAN OPENING	Permissive Crossover—Virginia	Crossover Nose	Crossover Nose plus Arrows	Crossover Arrows	Permissive U-Turn
Confusions	2	2	0	2	8	5	1
Subjects who did not know the meaning	0	0	0	1	0	0	0

When asked whether "crossover," "crossing," or "opening" conveyed the intended meaning best, 20 subjects chose "crossover," 7 chose "opening," and 3 chose "crossing." Subjects also were asked if the addition of the word "median" would help clarify the meaning, and 24 subjects (80 percent) said that it would.

The most common reply to questions about the distance a sign should be located in front of the crossover was time to slow down and stop before the crossover. Two-thirds of the subjects gave distances of over 400 ft (122 m) when traveling at 55 mi/h (89 km/h). The American Association of State Highway and Transportation Officials stopping sight distances are 450 to 550 ft (137 to 168 m) at 55 mi/h (89 km/h) on wet pavements. Twenty-eight of the subjects (93 percent) thought that adding a distance plate beneath the sign would help them locate the crossover.

Conclusions

The majority of subjects in this study perceived crossovers as potentially hazardous locations and felt that signs indicating the presence of a median crossover would likely have a beneficial effect on their driving behavior.

Subjects also felt that the signs should not be placed closer than the stopping sight distance in front of a crossover or at a distance of 500 to 1,000 ft (152 to 305 m) on a 55 mi/h (89 km/h) highway.

The use of the word "median" in a word message sign is best understood by uncued subjects. Most of the subjects chose "crossover" rather than "crossing" or "opening" as best conveying the intended meaning. Therefore, it is recommended that if a word message sign is used, it should be MEDIAN CROSSOVER. The lettering in the word "crossover" would have to be small to fit on a standard diamond sign, or an oversized sign would have to be used.

The results of the legibility, understanding, and recognition distance sections of this study as well as results of other studies (*2*) clearly show that although word message signs usually can be understood once they are read, they are less legible than symbolic signs. The Crossover Arrows sign had the best mean legibility distances and understanding distances of the symbolic signs tested in this study; but it had by far the most misinterpretations by uncued subjects. It also was not highly ranked by subjects in the preference test.

Of the other symbolic signs, the Permissive U-Turn sign had low mean legibility distances and understanding distances and was least understood by the subjects. It was ranked last by the majority of subjects in the preference test. The significance of the green background to indicate a permissive sign was not understood at all.

The Virginia sign also had low mean legibility distances and was not well understood by uncued subjects. It was not highly ranked in the preference test but did very well in the recognition test, presumably because of its different color and shape. It was recognized at a far greater mean distance than any of the other signs and was the only sign not confused at all after the subjects had been cued to its meaning. Several subjects mentioned that if they had initially known the meaning of the sign, they thought this sign would be the best one to use. However, as the meaning of the sign was not at all obvious to the uncued subjects, it would require extensive education of drivers to make the sign a useful traffic engineering tool.

Although the Crossover Nose plus Arrows sign had slightly better mean legibility distances, the Crossover Nose sign had slightly better mean understanding and recognition distances and was misinterpreted and confused less often in the understanding and recognition tests. The Crossover Nose sign also was given the best average rank out of all of the signs in the preference test.

Therefore, of all of the symbol signs tested, the Crossover Nose sign is recommended to indicate the presence of a median crossover and also is recommended for field evaluation.

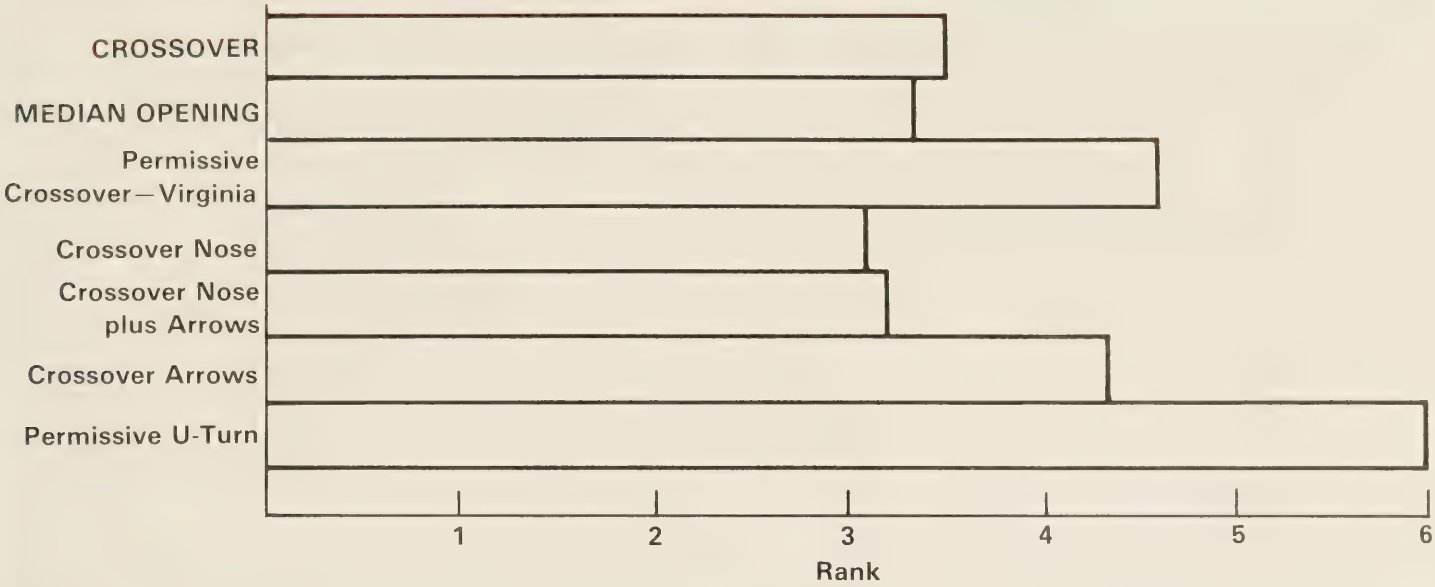


Figure 5.—Mean preference rankings.

REFERENCES

(1) P.D. Cribbins, J.M. Avey, and J.K. Donaldson, "Effects of Selected Roadway and Operational Characteristics on Accidents on Multi-Lane Highways," Highway Research Board Record 188, *Highway Research Board*, Washington, DC, 1967.

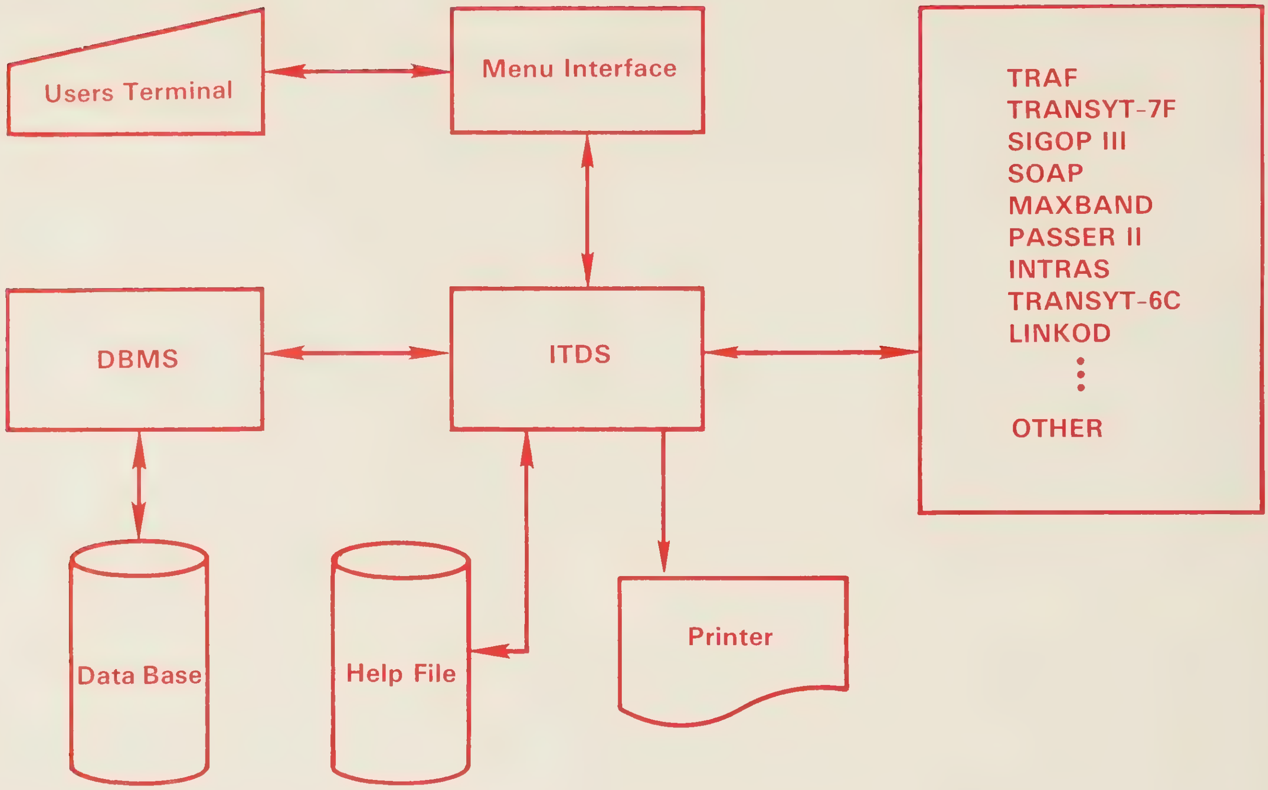
(2) R.J. Jacobs, A.W. Johnston, and B.L. Cole, "The Visibility of Alphabetic and Symbolic Traffic Signs," Report 5(7), *Australian Road Research,* 1975, pp. 68-87.

Gillian M. Worsey performed this study in 1985 as a student participating in the FHWA Research Fellowship Program. Ms. Worsey is a Ph.D. candidate at the University of Missouri-Rolla. As part of her dissertation she also will perform a similar study in Rolla to determine if there are any regional differences in the results reported in this article.

Charles E. Dare is the Director of the FHWA-sponsored Transportation Technical Assistance Office at the University of Missouri-Rolla. He also serves as faculty advisor to the Institute of Transportation Engineers Student Chapter at UMR and is in charge of the transportation area in the Civil Engineering Department. Dr. Dare is active in the Transportation Research Board Committee on Traffic Control Devices and the Committee on Transportation Planning Needs and Requirements for Small- and Medium-Sized Communities.

Richard N. Schwab is an electrical engineer in the Traffic Safety Research Division, Office of Safety and Traffic Operations Research and Development, Federal Highway Administration. He has been with FHWA since 1962 and is project manager for FCP Project 1P, "Night Visibility." His technical background is physiological optics and sensory capability of the human visual system. Mr. Schwab's work at FHWA has involved establishing the effects of adverse environmental conditions such as darkness, fog, snow, dust, and rain on traffic flow and highway safety and developing methods for overcoming these effects. Before joining FHWA, he was a graduate assistant on the staff of the Institute for Research in Vision at Ohio State University.

Samuel C. Tignor is Chief of the Traffic Safety Research Division, FHWA. He manages research pertaining to traffic signs, markings, and signals; highway operations; work zone safety; railroad-highway at-grade crossings; lighting; and speed control. Dr. Tignor is a 1961 graduate of the FHWA Highway Engineering Training Program.



ITDS: A Data Base Driven Interface to Traffic Models Using a Microcomputer

by
Alberto J. Santiago

Introduction

Developing and implementing traffic control strategies is complex and costly, involving significant investments in planning and in hardware acquisition, installation, and maintenance. In most cases, limitations of time, personnel, and cost, together with the obvious practical problems associated with disturbing existing traffic movements, preclude extensive field experimentation with alternative control strategies.

In response to this problem, the Federal Highway Administration (FHWA) and others have developed over the past 20 years a number of computer programs that can evaluate and/or optimize different traffic control strategies before committing the financial resources necessary to design the strategies and implement them in the field.

Extensive use of these computer programs has demonstrated their potential as effective tools in developing traffic control strategies that reduce motorist operating costs; vehicle fuel consumption and emissions; planning, design, and implementation costs of new control strategies; and costly and inconvenient retrofits when problems in a strategy are detected only after implementation.

However, differences in data requirements and input formats, the need to be comfortable working in a computer environment, and the perceived difficulty of using these computer programs—hereafter referred to as traffic models—have deterred some traffic engineers and analysts from using these powerful tools.

This article describes the Integrated Traffic Data System (ITDS), a set of microcomputer programs that solves many of these problems by providing an easy-to-use interface to a wide range of existing traffic models. ITDS allows the user to maintain a local traffic data base and easily generate input data sets for various traffic models in a user-friendly manner.

Common Problems With Traffic Models

Although traffic models are far more efficient and effective than other forms of complex analytical procedures, their use involves inherent problems in model selection, data requirements, and data coding.

Model selection

Traffic models were designed to run on mainframe computers and, in most cases, perform independent functions (simulation or optimization) for different applications (isolated intersections, arterials, grid networks, and/or freeways in urban, suburban, and/or rural scenarios) at different levels of detail (macroscopic or microscopic). These limitations in function, application, and detail imply that various traffic models must be used to develop networkwide, comprehensive control strategies.

Model selection also depends on available computers, model documentation (users manuals or software manuals), training (accessibility and willingness to attend training sessions), and support from the model developer.

Extensive documentation on model selection is available, however, to assist analysts in decisionmaking.

Data requirements

The availability of all of the data required by the models must be considered. Because traffic models were developed by different sources over time, their data requirements are similar but not identical. This implies that model selection dictates the data requirements which, depending on the data currently available, may impose the need for additional data collection efforts—an expensive proposition that affects the other equally important considerations, quality and compatibility. The output of any traffic model is only as good as the data that are used as input. If the data used as input reflect the "real-world" operation of the network, the model results will be accurate. Factors such as data collection procedures, separate data collections over long periods of time, and accuracy of equipment used directly affect the quality of the data and thus the representation of the traffic network by the models, no matter how sophisticated the models are. It is also important to note that problems associated with the quality and compatibility of the data are user-dependent and cannot be readily resolved.

Data coding

Coding, or manually processing, data is a tedious, time-consuming process requiring considerable personnel, expertise, and financial support and is the main reason traffic models are now used only to a limited degree. Input formats and the results reported vary considerably from model to model. The user is required to reformat the original data to be compatible with the input format of the model to be used, run the program, get a copy of the results, manually reformat the portion of that output required by a second model, reformat any other data required by the second model that was not used or reported by the first model, run the second program, and continue in this manner until the process is completed for all models used and any possible or feasible alternatives. This repeated manual handling and processing of data introduces repeated chances for error, further jeopardizing the integrity of the data.

Advantages of Traffic Models

If such is the case, why bother to use traffic models? Very simply, it is less expensive than any other form of complex analytical procedure. The extra costs associated with the use of traffic models—training and computer use—are easily offset by the speed, flexibility, and accuracy of the results obtained. Additionally, training is a one-time cost per model used and usually pays for itself on the first application.

Common traffic control problems such as determining the impacts of implementing a pair of one-way streets in a downtown area, developing traffic control strategies to account for the closure of a section of roadway in an arterial, or updating the signal phasing and timing plans in an urban area to provide progression and reduce delay require considerable effort to resolve manually, and their solutions usually are inflexible in the sense that they are specific to the condition and cannot accommodate variances readily. (For example, "what if" two or three pairs of one-way streets, rather than one pair, were to be implemented?) Traffic models provide this flexibility with minimal additional effort and certainly at less cost than manual methods.

Any action taken to resolve, or at least minimize, problems associated with using traffic models will greatly promote their use, resulting in the development and implementation of better traffic control strategies.

ITDS—A New Concept

FHWA developed ITDS to resolve problems associated with data availability and coding. ITDS is a microcomputer-based system that quickly and easily generates input data sets extracted from a locally managed traffic data base for traffic simulation and signal timing optimization programs. The system is designed for traffic engineers and analysts who use, or intend to use, existing traffic models to develop and test traffic control strategies.

The main features of ITDS include the following:

- Menu-driven software with online assistance for easy, user-friendly access.

- Networkwide traffic data base storage on a hard disk that allows high-storage capacity and access speed.
- Data base maintenance using the state-of-the-art CODASYL (*C*onference *O*n *DA*ta *SY*stems *L*anguages) type data base management system.
- Input data sets for traffic models generated from either querying the data base or from user-supplied data.
- Job submission to and retrieval from a remote mainframe computer where the models could be executed by means of communication lines.
- Ability to use an optimization model's output as input to other traffic models.
- Data base management security.
- Data requirements listing, on a per model basis, for all interfaced models.
- Adaptability to meet future needs including interfacing to other traffic models and the use of color graphics, light pens, and "mouse."

With the exception of the job submission and retrieval features, all of the system's features relate directly or indirectly to the data base and its management. Therefore, the most important task in developing ITDS was to design a data base structure that could store any kind of traffic engineering data in a generic manner and still be readily accessible to any external application software (traffic models). This requirement led to the development of the data base approach.

The Data Base Approach

A data base is a centralized collection or storage of data for use in one or more particular applications. In traffic engineering, these data include the physical and operational characteristics of a traffic network. In most traffic modeling applications, specific means of handling data storage requirements have been developed. Typically, this data storage has been in the form of fixed-length sequential or "flat" files, which is appropriate for most standalone uses.

Because ITDS was designed to interface to a wide range of models, it has a more substantial data management and requirement problem than do most previous applications. For this reason, the heart of ITDS is a formal Data Base Management System (DBMS)—a collection of software that organizes, stores, and retrieves data items in a data base. ITDS represents the first known formal application of data base management theory to traffic engineering.

A DBMS in this application provides the following advantages:

- A means for sharing data among several different user applications. This first point is the most important. The DBMS provides a "universal" view of the traffic data base, which is independent of any particular application but from which each application can draw the subset of data it needs.
- A systematic and efficient means of storing and retrieving data from the data base.
- Flexibility for expanding the data base structure.
- Control over updates and changes, thus maintaining the integrity of the data base.

System Design and Implementation

In addition to developing a data base approach, other ITDS design goals can be summarized as follows:

- Portability—ITDS must be usable on a wide range of microcomputer systems. Also, the software must be designed so that any machine-specific code is localized in a single subroutine library.
- Low cost—ITDS should function with off-the-shelf hardware systems that are affordable to local traffic engineering organizations.
- Ease of use—ITDS should be easy to learn and use, and the advanced user should not be burdened with unnecessary tutorial information.
- Expandability—ITDS should be designed to grow and adapt to new environments. This includes interfacing to new traffic models as they are developed as well as interfacing to existing models as they are implemented in microcomputer versions.
- Versatility—ITDS should be able to store all kinds and amounts of traffic data. Preferably the quantity of data that can be stored should be limited only by the storage capacity of the computer.
- Economical—ITDS should take advantage of existing software components, where possible, to save developmental time and funds.

These design goals had a strong influence on the selection of software and hardware components and on the overall implementation approach.

Software components

ITDS has four categories of internal software components—the screen editor, the model interfaces, the DBMS, and the data base editor.

The screen editor, a general purpose interface between the ITDS software and the user's terminal screen, allows screen "forms" to be presented to the user. Each form typically consists of labeled fields for supplying various data values, along with explanatory text. Default or previously input values automatically are supplied for each field. The user can change or insert values in the various fields by moving a cursor to the field using the up, down, left, and right arrow keys at the console keyboard and then simply typing in the new value. Range checking and validation are performed automatically, and errors are reported at the bottom of the screen. Online help is available for any field at any time.

The screen editor is a much enhanced version of one developed originally for the U.S. Department of Transportation's Urban Mass Transportation Administration.

The second set of ITDS software components, the model interfaces, produces "card image" input files for the various traffic models. These fixed 80-column record length files contain all of the input data and commands to run their respective models. The model interfaces ensure that the correct data values are placed in the appropriate columns on each line (card) of the file.

The data placed in these files come from as many as four sources—the ITDS data base, the user's console, values from a previous input deck, and the models' built-in defaults. The user always has the final selection because values can be modified on the screen before being accepted.

The model interfaces also retrieve selected model output information for storage in the local data base. Current plans are to attempt to retrieve and store only the signal timing plans in this manner, allowing a user, for example, to retrieve optimal timing plans output by an optimization model such as TRANSYT-7F, store these data, and retrieve them for input to a detailed simulation model such as NETSIM.

As noted earlier, one of the most important components of ITDS is the DBMS. ITDS is built around the MDBS-III DBMS, an extended CODASYL network-type DBMS, which is designed as a library of software tools for interfacing to a user's application program. The MDBS-III DBMS was selected because it was the only microcomputer-based system available at the time that met design requirements for portability, security, data storage capacity, and, most importantly, ability to interface to a standardized programming language.

The final component of ITDS, the data base editor, is a menu-driven program that allows the user to create and update a data base of traffic engineering data. The menus are presented in a hierarchical sequence for easy access to the various data base components.

Several ITDS software components are external to the ITDS code itself, including the communications software, the design modification utility (DMU), and, of course, the traffic engineering models themselves.

The communications software downloads the card image input files to a remote mainframe or minicomputer where the modeling and analysis actually could be performed. As microcomputers become more powerful, all of the traffic models may be able to be run locally on the microcomputer itself, eliminating the need for communication with a remote site and simplifying the use of ITDS.

The DMU allows the user to perform certain modifications to the data base, including expanding the data base size and changing passwords and user names.

Software and hardware specifications

ITDS was developed using the Pascal MT+ language running under the CP/M-86 operating system. This language was chosen for the following reasons:

- Pascal MT+ was the only Pascal compiler at the time that conformed to the proposed ISO standard.
- Pascal MT+ is available for a variety of 8- and 16-bit computers, which assured the standardization and portability of the code.
- The nature of Pascal helps the programmer design efficient modular code that is maintained and updated easily.
- A first version of what was to be the screen editor portion of ITDS already was coded using Pascal.
- Pascal MT+ worked well with other ITDS components selected, such as the operating system and DBMS.

ITDS's initial development and testing were performed on an IBM-PC using the CP/M-86 operating system. This system can be implemented on 8-bit machines such as the Apple-II; however, 16-bit implementation allows greater speed and efficiency. Since the decision was made to use CP/M, the MS-DOS operating system has emerged as the dominant system for 16-bit environments. ITDS easily was converted from CP/M-86 to MS-DOS environment because machine and operating system specific code had been isolated in one subroutine library. The imminent release and support of ITDS will be only for the MS-DOS version.

ITDS does not include communication software. Files can be transmitted to and from a remote mainframe computer using a number of free "public domain" modem packages such as MODEM-7, PC-TALK, and KERMIT. Communication also can be accomplished by means of a local area network.

Expandability and modularity

ITDS has been designed with the future in mind. Because ITDS's data base structure is independent of any particular model's requirements, new and revised models generally can be interfaced to ITDS by adding only a new "deck" formatting module. Modifications to the data base structure, if required, should be minor and would not affect the operation of the system's other components.

As more and more mainframe traffic engineering models are implemented on microcomputer systems, ITDS can provide a standardized, easy-to-use interface. This eliminates a common problem of converting mainframe software to microcomputer use—providing an easy-to-use "front end" to the program.

ITDS's modular design makes it easy to add new components to the system. One enhancement that lends itself nicely to ITDS is the use of high-resolution color graphics, which can be extremely useful when entering complex network data such as geometrics or signal timing plans. Enhancements of this kind currently are underway.

Status

ITDS's software and documentation have been completed. The system will be released to the general public shortly, pending the signing of the distribution agreement for the DBMS. This agreement will enable FHWA to distribute ITDS, with the DBMS, for a small fee to cover the copying and handling expenses. The initial release of ITDS will include four major programs—DBedit, DBprint, NETSIM interface, and TRANSYT-7F interface.

The DBedit program allows the user to create and maintain the central data base and provides an option for segregating the data base for the entire network into user-definable subnetworks. The DBprint program creates hardcopies of the information stored in the data base and provides for a limited data base querying capability.

The NETSIM and TRANSYT-7F interfaces are the programs that create the input data sets (for the respective traffic models) by querying the data base. The TRANSYT-7F interface supports both the mainframe and microcomputer versions of the model. The NETSIM interface was designed for the "TRAF" NETSIM, which is expected to be released later this year.

Interfaces for additional traffic models, such as PASSER II, MAXBAND, SOAP, SIGOP III, and the computerized Highway Capacity Manual, are being developed as part of the ITDS support and maintenance activities. Graphics capabilities also are being developed, and the data base querying capabilities are being enhanced. These capabilities will be available on future ITDS releases during 1987.

Summary

ITDS efficiently allows for the storage of a generic traffic data base that interfaces with user-friendly, menu-driven programs for the creation of input data sets for various traffic models.

ITDS fills the gap between mainframe and microcomputer technology as related to traffic modeling. Traditionally, traffic models have been developed to run on mainframe computers. ITDS has taken full advantage of state-of-the-art microcomputer hardware and software, enabling the preprocessing of data to create input files offline, job submission and output retrieval, and the automatic use of optimization programs' output as input to other models. ITDS is thus the middle step between the traditional approach of creating input files manually and using a mainframe computer for processing and the innovative approach of creating input files and executing the programs locally and interactively at a microcomputer.

Additionally, ITDS reduces considerably the overhead costs associated with traffic models—training costs and costs associated with coding and submitting input files for processing. It provides information on the data requirements, therefore reducing to a minimum the data collection efforts. It provides an accessible, manageable, and centralized data base, and, last, but not least, ITDS provides for a simple, user-friendly work environment.

An important contribution of the ITDS project has been the development of a data base schema covering the data needs of a range of traffic engineering and network analysis models. The resulting data model has been designed to adapt to the changing needs of traffic engineering simulation and optimization tasks and also can be adapted to other transportation applications such as planning, mass transit, and safety, specifically in accident record management.

From a highway transportation perspective, the scenario for the 1980's is a very challenging one, calling upon the traffic engineering community to maximize the performance of our highway system. Our Nation's dependence on the movement of people and goods cannot tolerate any less. To cope with this challenge, major traffic engineering actions requiring accurate analysis tools must be planned and pursued aggressively. ITDS is the powerful tool that permits the use of traffic models in an efficient and effective manner, resulting in better traffic control strategies.

Readers interested in additional information on ITDS should contact the author at the following address:

Federal Highway Administration
Office of Safety and Traffic Operations R&D
Traffic Systems Division, HSR-10
6300 Georgetown Pike
McLean, Virginia 22101-2296
(703) 285-2027

Alberto J. Santiago is a highway research engineer in the Traffic Systems Division, Office of Safety and Traffic Operations Research and Development, FHWA. As project manager of FCP Project 2Q, "Urban Network Control," he coordinates, monitors, plans, and conducts research activities related to computerized signal systems, highway capacity, traffic simulation, and signal timing optimization programs. Mr. Santiago's principal areas of interest include traffic modeling, microcomputer applications to traffic engineering, and computer graphics.

Accident Analysis of Highway Narrow Bridge Sites

by
Charles P. Brinkman and King K. Mak

Introduction

Information on traffic accidents at bridge sites suggests a potential safety problem and the need for more detailed data on the problem. In the early 1970's, bridge-related accidents in the States of Virginia and Kentucky, for example, not only constituted a high percentage of all accidents, but also accounted for a disproportionate number of fatalities and injuries. (*1, 2*)[1] Bridge-related accidents were found to be approximately twice as likely to result in a fatality as a typical accident.

Of particular concern are "narrow" bridges whose diminished widths may increase the risk of single-vehicle collisions with roadside appurtenances such as bridge ends, railings, or approach guardrails as well as collisions with other vehicles. Also, many narrow bridges are structurally deficient because of their ages.

A research study sponsored by the Federal Highway Administration (FHWA) examined the extent and nature of the narrow bridge accident problem.[2] This article presents selected major findings and recommendations from this study.

Study Approach

Data on the physical and operational characteristics of bridges and their approach roadways were compiled from the computerized bridge and roadway inventory data files from the States of Arizona, Michigan, Montana, Texas, and Washington. Accident data were assembled from State accident files for all reported accidents occurring on or within 500 ft (152.4 m) of these bridges for a 3-year period using a milepoint matching process. The data base contained bridge, roadway, traffic, and accident data on 11,880 bridges and 24,809 accidents that occurred on these bridges or within their approach areas.

[1]Italic numbers in parentheses identify references on page 133.

[2]K.K. Mak and L.R. Calcote, "Accident Analysis of Highway Narrow Bridge Sites," Final Report, Federal Highway Administration and National Highway Traffic Safety Administration, Contract No. DOT-FH-11-9285, Washington, DC, February 1983.

Bridges included in the study data base had to meet the following criteria:

- The bridges had to be on State highway systems.
- The bridges had to be overpass structures (excluding culverts) carrying mainline vehicular traffic. For twin structures included in the bridge inventory file as two separate bridges, only the first of the two bridges was selected for analysis.
- No traffic control signals could be on the bridges or within the approach areas to the bridges.
- All key data elements on the bridges had to be known.

Another important consideration was the definition for what constitutes a narrow bridge. The "narrowness" definition used in this study was as follows:

- One lane, a total width of 18 ft (5.5 m) or less.
- Two lanes, a combined total width of 24 ft (7.3 m) or less.
- Total approach roadway width is greater than total bridge width and either the bridge shoulder width is less than 50 percent of the approach roadway shoulder width or the bridge shoulder width is at least 50 percent of the approach roadway shoulder width.

This definition generally was consistent with that used in NCHRP Report No. 203. (*3*) However, the further breakdown of up to 50 percent and greater than 50 percent shoulder reduction was arbitrary.

It should be emphasized that the study findings apply only to bridges meeting the study criteria and should not be extrapolated or extended to bridges not meeting these criteria.

General Bridge Characteristics

Because only bridges on State highway systems were included in the study, more than 90 percent of the bridges studied were in rural areas (table 1). Because there are few one-lane bridges on State highway systems, two-lane single structures accounted for 81.7 percent of the bridges studied, 95.6 percent of which were on rural arterials or collectors. Two-lane twin structures accounted for another 12.1 percent of the study bridges, two-thirds of which were on Interstate highways. The study thus concentrated on two-lane single and twin structures.

Overall, 71.9 percent of the single structures and 39 percent of the twin structures were defined as narrow. Narrow bridges were more prevalent in rural areas than in urban areas, and the percentage of narrow bridges decreased with higher functional class. Most bridges were straight and level, indicating the old practice of making alignment changes on the approach roadways.

The average two-lane single structure studied was 169 ft (51.5 m) long, 27.7 ft (8.4 m) wide with 11-ft (3.4-m) lanes, and had an approach roadway 29.8 ft (9.1 m) wide. The average daily traffic (ADT) volume usually was under 1,000 vehicles per day. For two-lane twin structures, the average bridge was 245 ft (74.7 m) long, 36.8 ft (11.2 m) wide with 12-ft (3.7-m) lanes, and had an approach roadway 40 ft (12.2 m) wide. Most of the twin structures had an ADT volume greater than 8,000 vehicles per day.

Extent of the Bridge Accident Problem

Table 2 shows the accident frequencies (accidents per year per bridge) and rates (accidents per million vehicles) of the study bridges by functional classification. Accident frequencies were higher on urban bridges than on rural bridges because of the higher traffic volumes in urban areas. However, when traffic exposure was taken into account, the accident rates were higher on rural bridges than on urban bridges. Also, accident frequencies generally declined with lower functional class while accident rates increased, probably reflecting the effect of differences in traffic exposure and design standards.

Table 3 illustrates the severities, expressed in terms of percent incapacitating and fatal injuries, of bridge-related accidents by functional classification and lane stratification. The severity of accidents on rural bridges was significantly higher than that on urban bridges (11.4 percent versus 5.8 percent incapacitating and fatal injuries), possibly because single-vehicle accidents were more frequent (51.9 percent) on rural bridges while multi-vehicle accidents were predominant (60.5 percent) on urban bridges. Single-vehicle accidents were much more severe than multi-vehicle accidents, with more than twice the percentage of fatal and incapacitating injuries (12.5 percent versus 6.2 percent). Other factors, such as higher speeds on rural highways, also may contribute to this difference in severity.

The study found that single-vehicle accidents were the predominant kind of accident for one-lane (73.5 percent) and two-lane (46.8 percent) single structures and for two-lane twin structures (53.8 percent), while multi-vehicle accidents were the overwhelming majority on the other kinds of structures. Two-lane single structures had significantly higher accident severities (11.4 percent incapacitating and fatal injuries) than did the other kinds of structures.

The study also found that for single-vehicle accidents, impacts involving bridge parapet ends were the most severe, resulting in incapacitating and fatal injuries in almost 30 percent of the reported accidents. By comparison, the severity of guardrail collisions was only 9.5 percent incapacitating and fatal injuries, and the severity of bridge rail collisions was 12 percent incapacitating and fatal injuries—the average for all fixed-object or run-off-the-road accidents. By using proper approach guardrails and transition treatments, the severity of bridge end accidents could be reduced significantly. For multi-vehicle accidents, head-on collisions were the most severe (23.6 percent incapacitating and fatal injuries), while the overall severity was 6.2 percent incapacitating and fatal injuries.

The Effect of Bridge Narrowness

The effect of bridge narrowness on safety was examined, and accident frequencies and rates for the various bridge types and narrowness categories are summarized in table 4. For one-lane bridges, the mean accident rate was higher for bridges wider than 18 ft (5.5 m) than for bridges narrower than 18 ft (5.5 m); however, the difference was not statistically significant and the sample size was too small for reliable results.

For two-lane undivided single structures, in general mean accident rates decreased with increasing bridge width for bridges narrower than the approach roadways. However, for bridges wider than the approach roadways, the highest mean accident rate was at bridge widths between 20 and 22 ft (6.1 and 6.7 m). Also, differences in mean accident rates between bridges narrower than the approach roadways and bridges wider than the approach roadways are significant for bridge widths up to 20 ft (6.1 m) but not significant for widths greater than 20 ft (6.1 m) (fig. 1).

For four-lane undivided single structures, the accident rate was highest for bridges with more than a 50-percent shoulder reduction. The accident rate decreased significantly for bridges with a shoulder reduction less than or equal to 50 percent and increased for bridges with no shoulder reduction, although these differences were not significant.

Shoulder reduction appeared to have some effect on accident rates for multi-lane single structures. However, the differences are not statistically significant, probably because of the small sample sizes.

For two-lane twin structures, bridges with widths of 24 ft (7.3 m) or less and bridges with a shoulder reduction greater than 50 percent had similar accident rates (fig. 2). The accident rates decreased significantly for bridges with a shoulder reduction less than or equal to 50 percent and remained little changed for bridges with no shoulder reduction. This suggests that there may be little difference in safety benefit between two-lane twin structures with no shoulder reduction or a reduction less than or equal to 50 percent. However, the 50-percent shoulder reduction breakpoint is arbitrary, and the results could change with different breakpoints.

Table 1.—Distribution of bridges

Functional classification	Number	Percent
Urban:		
Interstate	323	2.7
Major arterial	622	5.2
Minor arterial	206	1.7
Collector	26	0.2
Subtotal	1,177	9.8
Rural:		
Interstate	839	7.1
Major arterial	2,109	17.8
Minor arterial	2,246	18.9
Collector	5,509	46.4
Subtotal	10,703	90.2
Total	11,880	100.0

Lane stratification	Number	Percent
One-lane	88	0.7
Single structure, undivided		
Two-lane	9,701	81.7
Four-lane	274	2.3
Single structure, divided		
Four-lane	174	1.5
Other	95	0.8
Twin structure		
Two-lane	1,440	12.1
Other	108	0.9
Total	11,880	100.0

Table 2.—Accident frequencies and rates by functional classification

Functional classification	Accidents per year per bridge[1]	Accidents per million vehicles
Urban:		
Interstate	5.04	0.517
Major arterial	2.66	0.656
Minor arterial	1.58	0.852
Collector	0.78	0.479
Average (weighted)	3.08	0.649
Rural:		
Interstate	1.09	0.456
Major arterial	0.71	0.634
Minor arterial	0.51	0.762
Collector	0.20	0.812
Average (weighted)	0.44	0.738

[1] Accident rates were computed on the basis of the bridge length plus 500 ft (152.4 m) in each direction.

Table 3.—Distribution of accident severity

Functional classification	Percent incapacitating and fatal injury
Urban:	
Interstate	5.6
Major arterial	5.9
Minor arterial	6.5
Collector	1.7
Average (weighted)	5.8
Rural:	
Interstate	10.7
Major arterial	12.2
Minor arterial	9.5
Collector	12.9
Average (weighted)	11.4

Lane stratification	Percent incapacitating and fatal injury
One-lane	5.9
Single structure, undivided	
Two-lane	11.4
Four-lane	5.6
Single structure, divided	
Four-lane	6.1
Other	3.5
Twin structure	
Two-lane	8.7
Other	5.7
Overall average (weighted)	8.9

Table 4.—Accident frequencies and rates by bridge narrowness

		Bridge narrowness				
		Number of lanes	Bridge width (ft)	Shoulder reduction	Accidents per year per bridge[1]	Accidents per million vehicles
Single structures		1	≤18	—[2]	0.12	1.177
			> 18	—	0.15	2.025
	Undivided	2	≤18, <Approach	—	0.38	1.884
			≤18, ≥Approach	—	0.09	0.751
			18-20, <Approach	—	0.25	1.036
			18-20, ≥Approach	—	0.11	0.765
			20-22, <Approach	—	0.48	1.194
			20-22, ≥Approach	—	0.28	1.213
			22-24, <Approach	—	0.35	0.816
			22-24, ≥Approach	—	0.21	0.874
			>24	>50%	0.70	0.746
			>24	≤50%	0.45	0.661
			>24	None	0.37	0.586
		4	N/A	>50%	2.95	0.876
				≤50%	1.47	0.597
				None	2.11	0.791
	Divided	4	N/A	>50%	2.99	0.681
				≤50%	2.15	0.565
				None	2.57	0.498
		Other	N/A	>50%	14.24	0.790
				≤50%	3.48	0.407
				None	4.28	0.398
Twin structures	Divided	2	≤24	—	1.66	0.577
			>24	>50%	2.35	0.562
			>24	≤50%	1.72	0.452
			>24	None	1.16	0.437
		Other	N/A	>50%	6.17	0.753
				≤50%	8.35	0.834
				None	4.75	0.562
			Total		0.70	0.729

[1]Accident rates were computed on the basis of the bridge length plus 500 ft (152.4 m) in each direction.

[2]Little or no shoulder width.

1 ft = 0.305 m

For multi-lane twin structures, bridges with no shoulder reduction had lower accident rates than did bridges with a shoulder reduction. However, the differences are not statistically significant, probably because of the small sample sizes.

Shoulder reduction seemed to have a marginally significant effect on accident severity on twin structures, with higher accident severities for bridges with a shoulder reduction greater than 50 percent and lower severities for bridges with a shoulder reduction less than or equal to 50 percent. Bridge narrowness did not appear to have any effect on accident severity for single structures.

Statistical Analysis

Extensive statistical analyses were conducted to determine the relationships of accident frequency, rate, and severity at bridge sites to bridge and approach characteristics. Various statistical techniques were used, including analysis of variance, correlation analysis, factor analysis, simple and multiple linear regression, and discriminant analysis. The results are highlighted below.

Results from the discriminant analysis indicate that bridges with accidents could reasonably be distinguished from bridges with no accidents based on certain physical and operational characteristics at bridge sites. For undivided bridges, the discriminant variables, in order of importance, are ADT, roadside distraction, percent shoulder reduction, degree of bridge curvature, curb presence, bridge length, degree of approach curvature, and delineation. For divided bridges, the discriminant variables are ADT, roadside distraction, percent shoulder reduction, barrier rating[3], Bridge Safety Index (BSI)[4], percent bridge grade, speed limit, and bridge length. It should be noted, however, that these discriminant variables are not necessarily causal factors.

[3]A composite index of ratings on the presence/absence and conditions of bridge rail, approach guardrail, transition rail, and end treatment.

[4]A composite index of ratings on 10 factors relating to bridge and traffic characteristics.

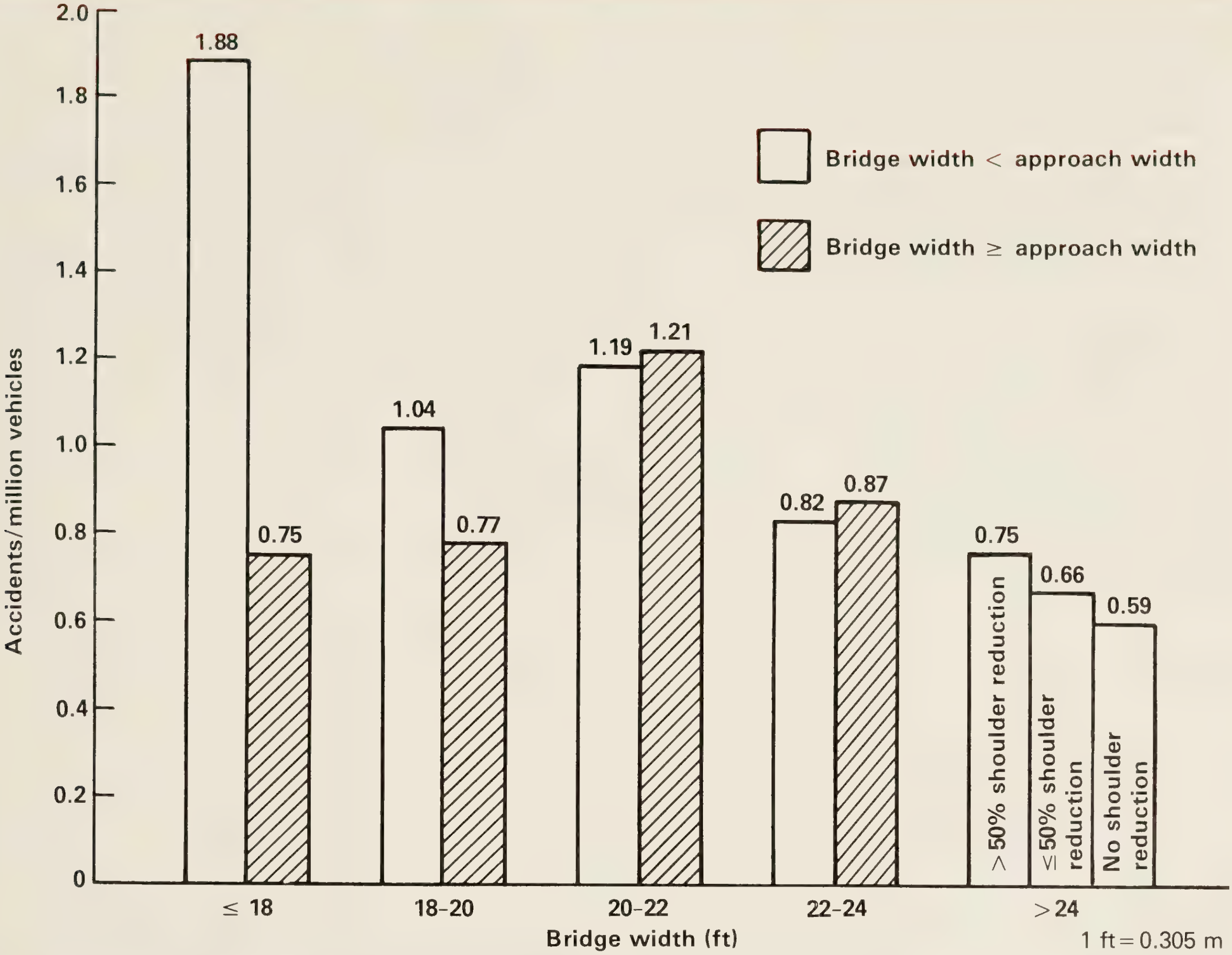


Figure 1.—Accident rate by bridge width for two-lane undivided single structures.

Results of discriminant analyses on accident severity (bridges with no incapacitating and fatal accidents versus bridges with incapacitating and fatal accidents) indicated that accident severity on bridges is little affected by the physical and operational characteristics at the bridge sites.

Stepwise multiple linear regression analyses were conducted to relate the physical and operational characteristics at bridge sites to accident frequency, rate, and severity for bridges with accidents. The regression results for accident frequency and rate are generally fair, with about 25 percent of the sample variations explained ($R^2 = 0.25$). However, the regression results for accident severity are poor, with R^2 values of under 10 percent in most cases, again indicating that accident severity is little affected by the physical and operational characteristics at bridge sites.

Although accident studies quantify the extent of a particular problem and provide valuable insight, they can only provide general guidance to specific safety design questions such as acceptable bridge width and shoulder reduction. Accident studies are limited by inaccurate accident location; unreported accidents; the lack of readily available data on important highway characteristics; the rare and random nature of traffic accidents, making large sample sizes necessary; and the interrelationships of accident causal factors, confounding the establishment of strong statistical relationships. Thus, safety design decisions also must be based on the pure physics of the problem, traffic operational measures of effectiveness, and human factors research.

Indepth Study of Bridge Accident Characteristics

Indepth data were gathered on 124 single-vehicle bridge accidents in which the first impact was with a bridge rail, bridge parapet end, or approach guardrail to provide insights into accident details not available from police accident data, such as impact speed and angle, vehicle kinematics, and damages to bridge hardware. Over three-quarters of the accidents involved more than one impact; one-half of these accidents involved three or more impacts. The injury severity of an accident increased with the total number of impacts, clearly indicating the role of subsequent impacts in the severity of these kinds of accidents.

One-quarter of the vehicles were yawing at greater than 30 degrees at impact. Vehicle yawing probably would have no adverse effect for impacts with typical bridge rail or guardrail sections; however, yawing could increase the severity of impacts with bridge rail or parapet and guardrail ends. Also, it could increase the possibility of rollovers. Vehicle yawing possibly should be a parameter in the design of barrier systems.

Also, a surprisingly high percentage of the impacts resulted in improper barrier performance (for example, overriding, vaulting, or penetration), and this potential problem should be examined closely. Also, subsequent impacts were prevalent for barrier collisions at bridge sites. Post-impact trajectory of vehicles should be studied closely for bridge rail and approach guardrail designs.

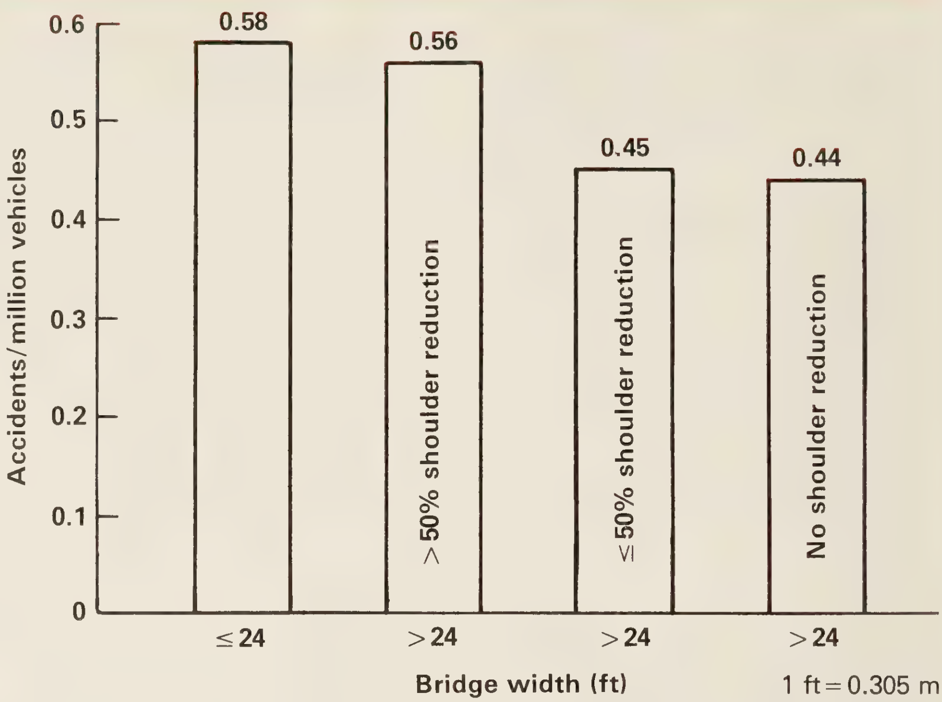


Figure 2.—Accident rate by bridge width and percent shoulder reduction for two-lane twin structures.

Conclusions and Recommendations

Bridges are more dangerous than the highway system as a whole, and narrow bridges can be a safety problem. This study provided directions for identifying bridges that may have a potential accident problem and are candidates for countermeasure applications. Discriminant functions and regression models developed in this study may be used to identify bridges with potential safety problems. However, it is essential to maintain design consistency in applying bridge accident countermeasures so that driver expectancy will not be violated; the application of countermeasures should be considered both on an individual bridge basis and on a systemwide basis.

Although the effectiveness of accident countermeasures was not evaluated in this study, some observations and suggestions regarding accident countermeasures may be inferred from the study results.

- Countermeasures requiring major reconstruction (for example, widening bridges more than the minimum widths required for bridges to remain in place given in the AASHTO "Green Book" (*4*) and realigning approach roadways) may not be cost-effective on the sole basis of safety benefits, given the lack of strong relationships found in this study between accidents and any of the physical features at bridge sites.

- If a bridge or its approach roadway is going to be reconstructed for other reasons such as structural deficiency, the bridge should be built to a design standard equal to that of the existing approach roadway or to the new design standard for the functional class of road if further improvements are planned for the approach roadway and/or the route involved. The study did not provide definitive guidance concerning acceptable bridge width and shoulder reduction. Certainly, as a minimum, where the full approach roadway width is greater than the width of the bridge, the width of new or reconstructed bridges should not be less than the minimum required roadway widths for new and reconstructed bridges. (*4*) However, this minimum requirement should not be construed as the optimal safety standard.

• It is also suggested that bridges not have curbs. Extremely sharp curves or steep grades should be avoided on bridges and their approach roadways, but gentle horizontal and vertical alignment should not be a problem.

• Bridge rail and parapet end impacts are by far the most severe bridge-related accident. Properly installed approach guardrail and transitions will significantly reduce accident severity and are highly recommended accident countermeasures. The frequencies of impacts with bridge rails and approach guardrails are nearly equal, which suggests that barrier countermeasures should include combined retrofits of the bridge rail and approach guardrail systems.

• Roadside distraction is strongly related to accident frequency, rate, and severity, suggesting that better land use control around bridge sites to minimize access points and potential conflicts may be an effective accident countermeasure.

REFERENCES

(*1*) M.H. Hilton, "Some Case Studies of Highway Bridges Involved in Accidents," Highway Research Record No. 432, *Highway Research Board,* Washington, DC, 1973.

(*2*) K.R. Agent, "Accidents Associated with Highway Bridges," Research Report No. 427, *Kentucky Bureau of Highways,* Lexington, KY, May 1975.

(*3*) D.L. Ivey et al., "Safety at Narrow Bridge Sites," National Cooperative Highway Research Program Report No. 203, *Transportation Research Board,* Washington, DC, June 1979.

(*4*) "A Policy on Geometric Design of Highways and Streets," *American Association of State Highway and Transportation Officials,* Washington, DC, 1984.

Charles P. Brinkman is a project manager in the Traffic Safety Research Division, Office of Safety and Traffic Operations Research and Development, FHWA. He is involved in research to improve highway safety evaluation.

King K. Mak is a research engineer with the Texas Transportation Institute, Texas A&M University System. He was with Southwest Research Institute when the study discussed in this article was conducted. Mr. Mak has been active in the highway safety area since 1970, with emphasis in accident data analysis, and has worked on various studies sponsored by FHWA, the National Highway Traffic Safety Administration, and other Federal and State agencies.

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 (RD&T). The Office of Engineering and Highway Operations Research and Development (R&D) includes the Structures Division, Pavements Division, and Materials Division. The Office of Safety and Traffic Operations R&D includes the Traffic Systems Division, Safety Design Division, and Traffic Safety Research Division. The reports are available from the source noted at the end of each description.

Requests for items available from the RD&T Report Center should be addressed to:

Federal Highway Administration
RD&T Report Center, HRD-11
6300 Georgetown Pike
McLean, VA 22101-2296
Telephone: 703-285-2144

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

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Implementation of Polymer Impregnation as a Bridge Deck Sealant, Report No. FHWA/RD-85/094

by Structures Division

The surface treatment procedure for partially polymer impregnating concrete bridge decks was refined and evaluated on eight full-sized highway bridges in various geographical locations over a period of 8 years. This report discusses the field evaluation phase of this effort. Cost data of bridge deck impregnation are included in the report. Results are reported on an extensive series of chloride ion intrusion tests performed. An appendix containing the most recent surface impregnation construction specifications also is included.

The report may be purchased from NTIS (PB No. 85 248698).

Polymer Concrete Used in Redecking a Major Bridge, Report No. FHWA/RD-85/079

by Structures Division

This report describes the successful use of polymer concrete for supporting the precast deck elements to the existing girders and stringers on the Woodrow Wilson Bridge, which crosses the Potomac River between Virginia and Maryland. Over 30 mixture designs were tested to formulate a suitable mixture based on the casting of mockup specimens and physical strength tests. An unusual gap problem was observed between the concrete slab and the underneath cast polymer pedestals in the sawcut mockup specimens. A solution was found by creating an inverted cone of polymer concrete, which increased a fill hole from a 2½-in (63.5-mm) diameter to a 6-in (152.4-mm) diameter base at the bottom of the precast slab interface with the pedestal.

The report may be purchased from NTIS (PB No. 85 249290).

Evaluation of the Howard Frankland Bridge Surveillance and Control System in Tampa, Florida, Report No. FHWA/RD-85/061

by Traffic Systems Division

The Federal Highway Administration and the Florida Department of Transportation jointly funded the design and construction of a computerized surveillance and control system (SCS) for the Howard

Frankland Bridge in Tampa, Florida. Three functions of the SCS are to detect incidents, manage traffic on the bridge, and divert bridgebound traffic during incidents causing serious delays. The SCS began full operations in June 1983. This report discusses the evaluation of the SCS.

The SCS identified 45 percent of all traffic incidents; however, it significantly improved response time for only one-third to one-half of all incidents. Considering all incidents, 89.6 percent were managed with lane closure; however, compliance with lane closure was low. For a significant portion of their duration, incidents were not protected by signing because of delays in detection, confirmation, and implementation. Nine percent of all incidents were managed with diversion. Compliance with diversion was low despite the finding that diversion offered substantial travel time savings. SCS component failures were a problem, and the SCS had a cost-effectiveness ratio of 1.2 to 1.0.

It was concluded that non-automated sources of incident detection, particularly motorist-aid phones, can be as reliable or more reliable than automated sources. Closed-circuit television can be useful in monitoring critical facilities such as bridges and tunnels. Diversion systems are feasible but applicable to a narrow range of problems, and SCS's require considerable maintenance and should be designed for reliability and easy servicing.

The report may be purchased from NTIS (PB No. 85 230274).

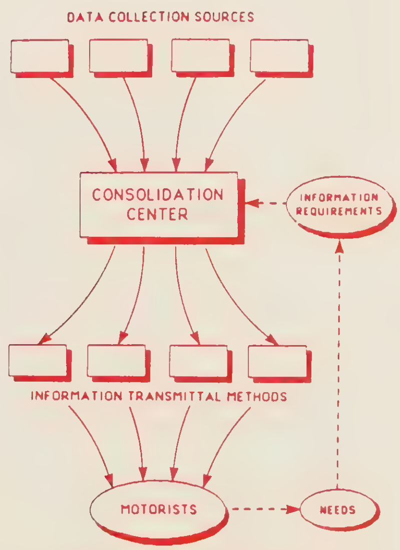
Concepts for a Low-Cost Motorist Information System, Final Report and Appendix A, Report No. FHWA/RD-85/038, and Appendix B—Case Study, Report No. FHWA/RD-85/039

by Traffic Systems Division

These reports discuss a study that developed and evaluated concepts for a low-cost, practical motorist information system that would decrease travel time and improve safety, comfort, and convenience. A list of motorist needs was developed and divided into dynamic information, which changes frequently and primarily includes information on traffic congestion and incidents; semidynamic information, which changes occasionally and primarily relates to motorist services, such as gas, food, lodging, and attractions information; and static information, which changes infrequently and includes information such as highway geometry and emergency services.

Existing systems for addressing motorist needs were identified and evaluated. These systems are described by three basic functions: Data collection, data consolidation, and information transmittal to motorists. These three functions form the basis of the concepts for improved motorist information systems.

The reports may be purchased from NTIS (PB Nos. 85 243657 and 85 243665).



Functional Diagram of a Motorist Information System

Symbolic Sign for Oversized-Truck Route Signs, Report No. FHWA/RD-85/064

by Traffic Systems Division

The Surface Transportation Assistance Act of 1982 mandates greater national uniformity in truck size and weight, requiring some States to raise their limits, at least for trucks traveling on the Interstate System and portions of the Federal-Aid Primary System. The law provides for the States to mark these routes with appropriate signs. The study described in this report evaluated six candidate symbolic signs that could be used for these nationally designated truck routes.

Truck drivers participated in tests of recognition time, meaning, and preference, and other drivers participated in tests of visibility, meaning, and preference.

The findings indicate that a side-view, double-trailer symbol sign had the best recognition time and the best meaning scores. Even though in the visibility study this symbol sign did not have the longest recognition distances, no other symbol was labeled as an oversized truck as often as the double-trailer symbol, possibly because the other candidate signs were confused with the presently used NO TRUCKS sign. Finally, the double-trailer symbol sign was overwhelmingly preferred by all test subjects over the other candidate signs.

The report may be purchased from NTIS (PB No. 85 241883).

Sensitivity of Resource Allocation Models to Discount Rate and Unreported Accidents, Report No. FHWA/RD-85/092

by Traffic Safety Research Division

Resource allocation models aid highway safety planning decisions by prioritizing projects based on their costs and benefits. A sensitivity analysis was conducted to see how project selection is affected by failure to adjust the accident data base for underreporting and, separately, by the choice of discount rate and accident-cost methodology used in computing accident costs and the present value of future benefits. The analysis used an optimization model developed by the Texas Transportation Institute for the Federal Highway Administration and a data base from Alabama that contained accident data from 216 high-accident locations as well as data on proposed countermeasures.

The choice of discount rate and accident cost methodology can have a significant impact on the highway safety projects selected and the benefits realized. This effect will be particularly noticeable if the choice of discount rate is an extreme one. The project selection is likely to be relatively stable in the discount rate range of 3 to 7 percent that was recommended for sensitivity analysis. Any project selected within this range will have little effect on total benefits and costs.

Unreported accidents also can play a decisive role in highway safety project selection. For the particular data set used in this analysis, projects selected changed little at budget levels of $300,000 to $900,000 when the percent of reported accidents was reduced. However, at budget levels of $1.2 million to $1.5 million, project selection changed considerably with a loss in total benefits. This suggests it is very important to account for the underreporting of accidents when a reporting threshold of towaway, injury, and fatal accidents is used.

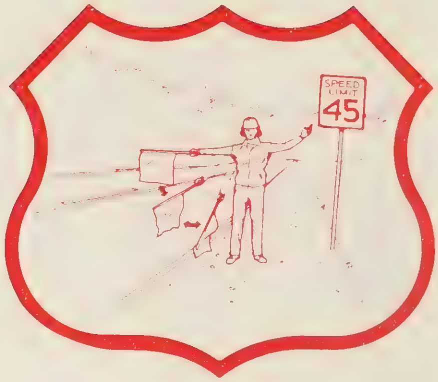
The report may be purchased from NTIS (PB No. 85 243806).

Benefits and Safety Impact of Night Work Zone Activities, Report No. FHWA/RD-85/067

by Safety Design Division

Through a literature review and discussions with highway and transportation officials in several States, information was obtained on questions and concerns relating to the planning, safety, and traffic control aspects of night maintenance and construction activities and their advantages and disadvantages. The information obtained was used to develop the general guidelines presented in this report on when and how maintenance and construction work should be performed at night. The report presents case studies illustrating the activities required in different kinds of night maintenance and construction activities. Although there are many potential disadvantages of working at night, it is believed that through the experience that has been gained and proper planning and special concern for construction worker and motorist safety, night work is feasible for selected maintenance and construction activities.

The report may be purchased from NTIS (PB No. 85 213320).



Improvements and New Concepts for Traffic Control in Work Zones, Volumes 1-4, Report Nos. FHWA/RD-85/034-037

by Safety Design Division

Volume 4, **Speed Control in Work Zones,** of this report series presents the results of a study to develop effective methods of slowing traffic to an acceptable speed in work zones. Factors considered in the study included cost, motorist and worker safety, institutional constraints, and probability of success in obtaining the desired speed.

Field tests were conducted to evaluate the short-term effectiveness of flagging, law enforcement, changeable message signs, and lane-width reduction in work zones on an undivided multilane urban arterial, an urban freeway, and two rural highways. Several different configurations of the four speed control methods were evaluated.

The results indicated that flagging and law enforcement were the most effective methods evaluated. These results are based on data collected over 2 to 3 hours. Additional evaluations are planned to determine if flagging and law enforcement are effective over a longer period of time.

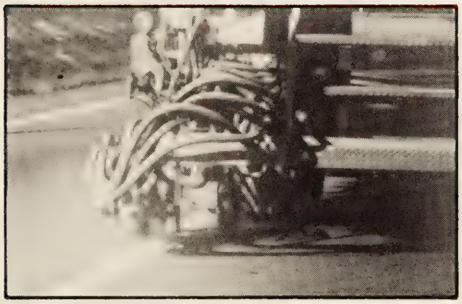
This report also contains a summary of the three other volumes in this series. Volume 1, **Effects of Traffic Control on Four-Lane Divided Highways,** Volume 2, **Implementation of Work Zone Traffic Control,** and Volume 3, **Abbreviated Marking Patterns in Work Zones,** may be purchased from NTIS (PB Nos. 85 207561, 85 207579, and 85 207587). Limited copies of Volume 4 are available from the RD&T Report Center.

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 (RD&T), Federal Highway Administration. Some items by others are included when the items are of special interest to highway agencies.

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

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161



Organic Yellow Traffic Paint, Report No. FHWA-TS-84-227

by Office of Implementation

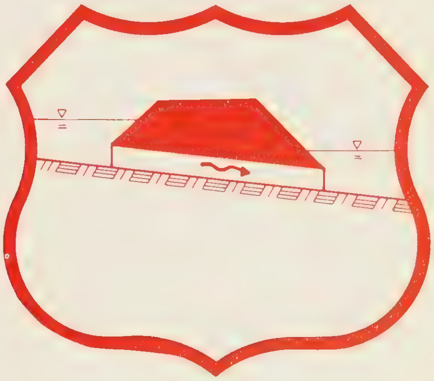
This report summarizes the results of a field evaluation of two organic yellow paints—a 50/50 mixture of white and yellow and a control section consisting of each participating State's standard yellow traffic paint. Also discussed are the paint formulations, laboratory and field tests, and the results of the States' evaluations. The study recommends that the color standard for yellow traffic paint be revised to allow a broader range, specifically the lighter yellow shades.

The report may be purchased from NTIS.

Hydraulic Design of Highway Culverts, Report No. FHWA-IP-85-15

by Office of Implementation

This comprehensive culvert design publication combines culvert design information contained in Hydraulic Engineering Circulars No. 5, No. 10, and No. 13 with hydrologic, storage routing, and special culvert design considerations. Culvert design methods are presented for both conventional culverts and culverts with inlet improvements. Also included are storage routing techniques that permit the designer to account for upstream ponding effects. Special design considerations for unique culvert applications, erosion and sediment control, debris control, and structural appurtenances are briefly discussed and referenced. The appendixes of the publication contain the equations and methodology used to construct the design charts, information on hydraulic resistance for corrugated metal culverts, and methods of optimizing culvert design using performance curves.



The report may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 (Stock No. 050-001-00298-1).

1983 National Value Engineering Conference—Proceedings Synopsis, Report No. FHWA-TS-85-208

by Office of Implementation

This report documents the proceedings of the 1983 National Value Engineering Conference held in Kissimmee, Florida, on November 16-18, 1983. The conference was sponsored by the Florida Department of Transportation in cooperation with the Federal Highway Administration's Office of Engineering and the Office of Implementation in the Offices of Research, Development, and Technology.

1983 National Value Engineering Conference

Included in the report are edited transcripts of the presentations, technical papers, and question-and-answer panel review sessions that were completed during the 3-day conference. Of particular interest were the presentations and panel sessions that covered new and unique applications of value engineering techniques to functionally analyze a State department of transportation's organizational structure and obtain balanced technical and cost-saving solutions to highway design and construction problems.

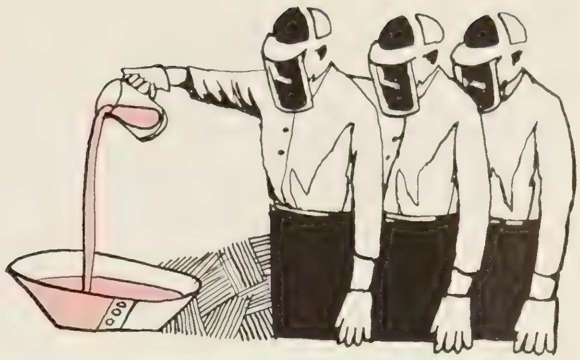
The report may be purchased from NTIS.

Dynamic Compaction of a Sanitary Landfill, Report No. FHWA-TS-85-227

by Office of Implementation

This report provides background information and describes construction operations involved in the dynamic compaction of a newly completed sanitary landfill that was crossed during the relocation and construction of U.S. Rte. 71 near Springdale, Arkansas. The report includes a history of the project, location and plans for the highway, geological survey data of the area, information concerning the landfill itself, and analyses of alternative solutions. Also included are details outlining the method used in determining the specialty contractor required for such a project. Load test results and implementation of a long-term monitoring plan to determine the extent and rate of settlement also are outlined.

The report may be purchased from NTIS.



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, DC 20418.

FCP Category 1—Highway Design and Operation for Safety

FCP Project 1A: Traffic and Safety Control Devices

Title: Driver Risk Perception and Performance. (FCP No. 31A3134)
Objective: Develop a measure of driver risk perception. Determine the relationship between risk perception and other driver characteristics such as age, experience, and degree of impairment. Examine the effects of traffic control devices, geometrics, and visual guidance factors (lighting and delineation) on driver risk perception. Ascertain how the driver's perception of risk translates into actual risk-taking and other behavior in the highway environment.
Performing Organization: Comsis Corporation, Wheaton, MD 20902
Expected Completion Date: March 1988
Estimated Cost: $198,000 (FHWA Administrative Contract)

FCP Project 1P: Night Visibility

Title: Enhancement to the DOT/FHWA Highway Simulator (HYSIM). (FCP No. 31P1033)
Objective: Provide an engineering design for the first planned enhancement in visual display capability for the FHWA HYSIM. Increase resolution, add scene complexity and higher brightness levels, and include interacting vehicles in the scene.
Performing Organization: Systems Technology, Inc., Hawthorne, CA 90250
Expected Completion Date: December 1986
Estimated Cost: $212,130 (FHWA Administrative Contract)

FCP Project 1T: Roadside Safety Hardware

Title: Rollover Caused by Concrete Safety Shape Barriers. (FCP No. 31T2452)
Objective: Determine causes of vehicle rollover and seek solutions. Review accident data. Use computer simulation with measured vehicle inertial and suspension properties to study the effects of front-wheel drive, wheel inertia, barrier coefficient of friction, nonlevel terrain, and asphalt overlays. Conduct full-scale tests to validate the analytical results, if required.
Performing Organization: Texas A&M Research Foundation, College Station, TX 77843
Expected Completion Date: March 1988
Estimated Cost: $150,000 (FHWA Administrative Contract)

FCP Category 2—Traffic Control and Management

FCP Project 2L: Electronic Devices for Traffic Control

Title: Malfunction Management of Traffic Signals. (FCP No. 32L1242)
Objective: Develop conceptual design and preliminary specifications for automatic malfunction detection of traffic signal control hardware. Determine which traffic control intersection hardware is most prone to failure. Analyze frequency of failure, cost of providing the hardware to detect failure, and alternative communication links and modes for the most cost-effective ways of communicating with isolated noninterconnected intersections to assess equipment status.
Performing Organization: Magnavox, Inc., Falls Church, VA 22042
Expected Completion Date: March 1987
Estimated Cost: $235,400 (FHWA Administrative Contract)

FCP Project 2P: Urban Freeway Management

Title: Corridor Traffic Management for Temporary Flow Disruptions. (FCP No. 32P2172)
Objective: Develop and document guidelines and case study examples for the application of corridor traffic management techniques to improve critical link flow disruptions. Include flow reductions as well as complete restrictions from either planned or unplanned incidents such as bridge

repair, major freeway reconstruction, large-truck accidents, and bridge collapse. Use existing traffic simulation models and traffic assignment techniques to demonstrate alternative management techniques.
Performing Organization: GAI Consultants, Inc., Monroeville, PA 15146
Expected Completion Date: September 1987
Estimated Cost: $158,000 (FHWA Administrative Contract)

FCP Category 3—Highway Operations

FCP Project 3B: Environmental Management

Title: Design Guidelines for Protective Systems for Spills of Hazardous Materials on the Highway System. (FCP No. 33B1062)
Objective: Develop design guidelines for protective systems for incorporation in the highway system. Evaluate alternative designs and determine effectiveness. Emphasize the feasibility of incorporation of protective measures in existing highways as well as into new designs.
Performing Organization: Kansas State University, Manhattan, KS 66506
Expected Completion Date: October 1987
Estimated Cost: $149,520 (FHWA Administrative Contract)

FCP Category 4—Pavement Design, Construction, and Management

FCP Project 4A: Pavement Management Strategies

Title: Cost Comparison of Maintenance Activities and a Selected Cost/Benefit Application. (FCP No. 44A2072)
Objective: Develop cost data model of routine maintenance activities for in-house and contractor forces. Develop a cost comparison analytical model for contract versus in-house accomplishment of routine maintenance activities. Prepare a case study cost/benefit analysis of roadside vegetation management alternatives. Conduct an analysis of the potential cost/benefits of a Bermuda grass release program for roadside vegetation.
Performing Organization: Texas Transportation Institute, College Station, TX 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1986
Estimated Cost: $145,000 (HP&R)

Title: Pavement Management Application of New Data Base. (FCP No. 44A3402)
Objective: Enhance ongoing software developments associated with the Utah Department of Transportation common data base composed of key parameters from planning, safety, and pavement condition. Concentrate on providing information for pavement management applications.
Performing Organization: Utah Department of Transportation, Salt Lake City, UT 84114
Expected Completion Date: September 1987
Estimated Cost: $23,600 (HP&R)

FCP Project 4B: Design and Rehabilitation of Rigid Pavements

Title: Design of Rest Area Comfort Stations. (FCP No. 44B1111)
Objective: Develop design criteria for safety rest area to result in safe, clean, efficient, easy to maintain, and cost-effective rest area comfort stations and facilities. Determine usage, vehicles using the facility, and operation and maintenance costs. Evaluate alternative energy sources and applications. Investigate innovative building materials and methods and security and legal liability. Develop, implement, and evaluate prototype designs and develop a design manual for rest area comfort stations.
Performing Organization: University of Texas at Austin, Austin, TX 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: September 1988
Estimated Cost: $310,000 (HP&R)

Title: Thin Bonded Overlay Implementation. (FCP No. 44B1338)
Objective: Determine under what conditions (distress manifestations and remaining service life) thin bonded overlays are the most appropriate rehabilitation technique. Develop an outline of construction specifications to ensure good quality thin bonded concrete overlays. Evaluate various materials and their relative advantages and disadvantages and the strength, durability, and economics of different overlay thicknesses. Develop a users design and construction manual for thin bonded overlays.
Performing Organization: University of Texas at Austin, Austin, TX 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1988
Estimated Cost: $230,000 (HP&R)

Title: Materials and Methods for Undersealing Concrete Pavements. (FCP No. 34B2192)

Objective: Document current undersealing materials, problems, and advantages of their application and performance in inservice pavements. Identify other materials that may have improved ease of application and improved performance. Select the most promising materials based on costs and laboratory testing. Evaluate these promising materials in experimental pavement rehabilitation projects.
Performing Organization: Austin Research Engineers, Inc., Austin, TX 78745
Expected Completion Date: March 1988
Estimated Cost: $150,000 (FHWA Administrative Contract)

Title: Rigid Pavement Data Base. (FCP No. 44B2314)

Objective: Evaluate the needs for pavement condition survey data. Select appropriate sections and obtain pavement condition data and update condition data procedures. Investigate incorporating the pavement condition data into a data base management system, and make appropriate recommendations. Develop an integrated overlay design manual for rigid pavements using the existing data base and existing overlay design procedures for each kind of rigid pavement.
Performing Organization: University of Texas at Austin, Austin, TX 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1988
Estimated Cost: $190,000 (HP&R)

FCP Project 4C: Design and Rehabilitation of Flexible Pavements

Title: Design and Performance of Asphalt Concrete Pavement (ACP) Overlays on Concrete Pavements. (FCP No. 44C4254)

Objective: Develop guidelines and procedures to be used in the thickness and mix design of ACP overlays on concrete pavements.
Performing Organization: Texas Transportation Institute, College Station, TX 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1988
Estimated Cost: $190,000 (HP&R)

Title: Treatment of Asphalt Mixtures With Lime and Antistripping Agents. (FCP No. 44C4374)

Objective: Determine the effectiveness of hydrated lime and selected liquid antistripping agents. Evaluate the relationships between test values for different mixtures and antistripping agents using indirect tensile test (wet-dry), Texas freeze-thaw pedestal test, Texas boiling test, and other tests. Evaluate field performance for different mixtures using different antistripping agents and relate test values to performance.
Performing Organization: University of Texas at Austin, Austin, TX 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1990
Estimated Cost: $300,000 (HP&R)

FCP Project 4D: Improved Flexible Binders

Title: Asphalt Behavior at Low Service Temperature. (FCP No. 34D1103)

Objective: Investigate the response of asphalts to varying cooling rates and repeated strains in the low temperature service range using newly developed methodology based on fracture mechanics. Determine how thermal cracking is initiated in asphalt pavements and how the initiation and propagation of cracks is affected by asphalt properties. Suggest methods to control this problem.
Performing Organization: Pennsylvania State University, University Park, PA 16802
Expected Completion Date: April 1988
Estimated Cost: $172,860 (FHWA Administrative Contract)

FCP Category 5—Structural Design and Hydraulics

FCP Project 5A: Bridge Loading and Design Criteria

Title: Design of Simple-Span Precast Prestressed Girders Made Continuous. (FCP No. 55A4012)
Objective: Investigate the behavior of precast, prestressed bridge girders made continuous by connections using cast-in-place slabs and diaphragms at the piers. Develop design procedures and guide specifications that can be used to compute elastic, inelastic, time-dependent, and ultimate moments commensurate with the degree of continuity developed by the connections at the piers.
Performing Organization: Contraction Technology Laboratory, Skokie, IL 60077
Expected Completion Date: December 1987
Estimated Cost: $242,000 (NCHRP)

Title: Anchorage Zone Reinforcement for Post-Tensioned Girders. (FCP No. 55A4022)
Objective: Develop design procedures for end and intermediate anchorage zones for post-tensioned concrete girders and slabs.
Performing Organization: University of Texas at Austin, Austin, TX 78712
Expected Completion Date: September 1988
Estimated Cost: $240,000 (NCHRP)

FCP Project 5K: Bridge Rehabilitation Technology

Title: Fatigue Evaluation Procedures for Steel Bridges. (FCP No. 55K2092)
Objective: Develop practical procedures that more accurately reflect the actual fatigue conditions in steel bridges and that can be applied for fatigue evaluation of existing or new bridges (specifically, determining fatigue-load ratings and estimating remaining life for existing bridges). Incorporate the procedures into AASHTO's manual for maintenance inspection of bridges and possibly future bridge design specifications.
Performing Organization: Case Western Reserve University, Cleveland, OH 44106
Expected Completion Date: September 1987
Estimated Cost: $200,000 (NCHRP)

Title: Distortion-Induced Fatigue Cracking in Steel Bridges. (FCP No. 55K2102)
Objective: Quantify the fatigue resistance of bridge details that are susceptible to distortion-induced fatigue cracking and evaluate the retrofit procedures used to repair such damage.
Performing Organization: Lehigh University, Bethlehem, PA 18015
Expected Completion Date: September 1988
Estimated Cost: $250,000 (NCHRP)

Title: Calibration of Bridge Capacity Estimates With Existing Test Data. (FCP No. 55K2112)
Objective: Assemble domestic and foreign test data to identify, quantify, and report significant aspects of observed behavior that are not now considered in load capacity estimates.
Performing Organization: University of Tennessee, Knoxville, TN 37996
Expected Completion Date: September 1987
Estimated Cost: $200,000 (NCHRP)

Title: Methods of Strengthening Existing Highway Bridges. (FCP No. 55K3052)
Objective: Evaluate the feasibility and cost-effectiveness of present strengthening methods as applied to various bridge types and identify cost-effective, innovative methods.
Performing Organization: Iowa State University, Ames, IA 50011
Expected Completion Date: December 1986
Estimated Cost: $150,000 (NCHRP)

U.S. Postal Service
STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION
Required by 39 U.S.C. 3685)

1A. TITLE OF PUBLICATION	1B. PUBLICATION NO.	2. DATE OF FILING
PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT		September 13,1985
3. FREQUENCY OF ISSUE	3A. NO. OF ISSUES PUBLISHED ANNUALLY	3B. ANNUAL SUBSCRIPTION PRICE
Quarterly	Four	$12(domestic) $15(foreign)

4. COMPLETE MAILING ADDRESS OF KNOWN OFFICE OF PUBLICATION *(Street, City, County, State and ZIP+4 Code) (Not printers)*
Federal Highway Administration
400 7th Street, SW., Washington, DC 20590

5. COMPLETE MAILING ADDRESS OF THE HEADQUARTERS OF GENERAL BUSINESS OFFICES OF THE PUBLISHER *(Not printer)*
same as item #4 above

6. FULL NAMES AND COMPLETE MAILING ADDRESS OF PUBLISHER, EDITOR, AND MANAGING EDITOR *(This item MUST NOT be blank)*

PUBLISHER *(Name and Complete Mailing Address)*
same as item #4 above

EDITOR *(Name and Complete Mailing Address)*
Cynthia Ebert/Carol Wadsworth
Federal Highway Administration, HRD-10, 6300 Georgetown Pike, McLean, VA 22101-2296

MANAGING EDITOR *(Name and Complete Mailing Address)*
William Zaccagnino
Federal Highway Administration, HRD-10, 6300 Georgetown Pike, McLean, VA 22101-2296

7. OWNER *(If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding 1 percent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a partnership or other unincorporated firm, its name and address, as well as that of each individual must be given. If the publication is published by a nonprofit organization, its name and address must be stated.) (Item must be completed.)*

FULL NAME	COMPLETE MAILING ADDRESS
U.S. Department of Transportation	400 7th Street, SW., Washington, DC 20590

8. KNOWN BONDHOLDERS, MORTGAGEES, AND OTHER SECURITY HOLDERS OWNING OR HOLDING 1 PERCENT OR MORE OF TOTAL AMOUNT OF BONDS, MORTGAGES OR OTHER SECURITIES *(If there are none, so state)*

FULL NAME	COMPLETE MAILING ADDRESS
N/A: U.S. Government Publication	

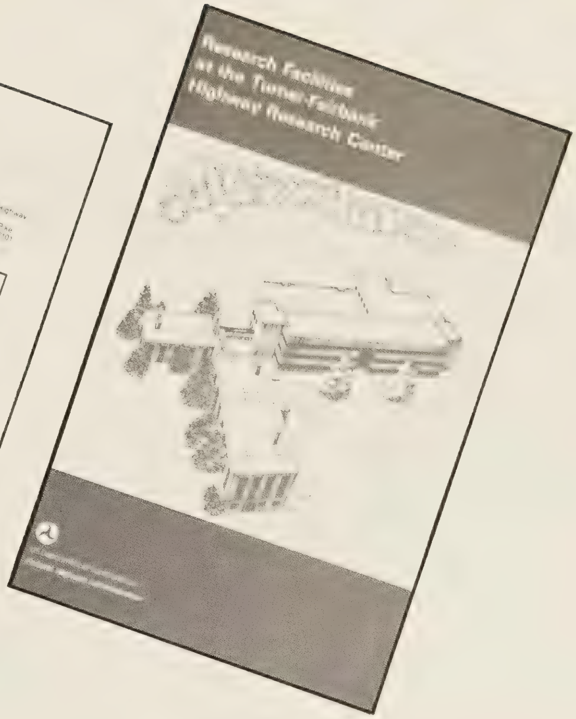
9. FOR COMPLETION BY NONPROFIT ORGANIZATIONS AUTHORIZED TO MAIL AT SPECIAL RATES *(Section 423.12 DMM only)*
The purpose, function, and nonprofit status of this organization and the exempt status for Federal income tax purposes *(Check one)*

☐ (1) HAS NOT CHANGED DURING PRECEDING 12 MONTHS
☐ (2) HAS CHANGED DURING PRECEDING 12 MONTHS
(If changed, publisher must submit explanation of change with this statement.)

10. EXTENT AND NATURE OF CIRCULATION *(See instructions on reverse side)*	AVERAGE NO. COPIES EACH ISSUE DURING PRECEDING 12 MONTHS	ACTUAL NO. COPIES OF SINGLE ISSUE PUBLISHED NEAREST TO FILING DATE
A. TOTAL NO. COPIES *(Net Press Run)*	5,514	5,455
B. PAID AND/OR REQUESTED CIRCULATION 1. Sales through dealers and carriers, street vendors and counter sales	0	0
2. Mail Subscription *(Paid and/or requested)*	1,100	1,100
C. TOTAL PAID AND/OR REQUESTED CIRCULATION *(Sum of 10B1 and 10B2)*	1,100	1,100
D. FREE DISTRIBUTION BY MAIL, CARRIER OR OTHER MEANS SAMPLES, COMPLIMENTARY, AND OTHER FREE COPIES	4,000	4,000
E. TOTAL DISTRIBUTION *(Sum of C and D)*	5,100	5,100
F. COPIES NOT DISTRIBUTED 1. Office use, left over, unaccounted, spoiled after printing	414	355
2. Return from News Agents	0	0
G. TOTAL *(Sum of E, F1 and 2 should equal net press run shown in A)*	5,514	5,455

11. I certify that the statements made by me above are correct and complete	SIGNATURE AND TITLE OF EDITOR, PUBLISHER, BUSINESS MANAGER, OR OWNER: Managing Editor

PS Form 3526, July 1984 *(See instruction on reverse)*



New Publications

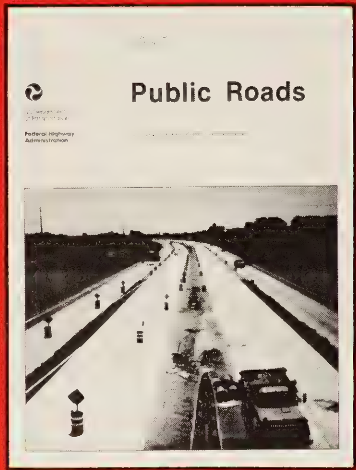
The Offices of Research, Development, and Technology (RD&T) have released their **1984-1985 Report of the Offices of Research, Development, and Technology.** This report is a continuation of the series of annual reports previously entitled "Federally Coordinated Program of Highway Research, Development, and Technology" and published for fiscal years 1974 through 1983. The latest report briefly discusses the goals and problems of the Federally Coordinated Program (FCP) of Highway Research, Development, and Technology and describes accomplishments in highway RD&T during fiscal years 1984 and 1985 in the areas of highway design and operation for safety; traffic control and management; highway operations; pavement design, construction, and management; and structural design and hydraulics. Also highlighted are other activities of the Offices of RD&T and the innovative research laboratories for FHWA inhouse research at the Turner-Fairbank Highway Research Center in McLean, Virginia. The proposed Strategic Highway Research Program (SHRP), expected to be implemented in fiscal year 1987, also is outlined.

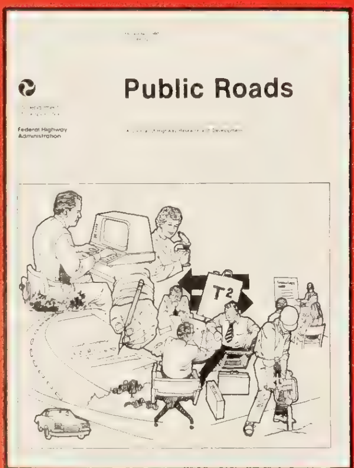
Also released by the Offices of RD&T is the brochure **Research Facilities at the Turner-Fairbank Highway Research Center** that describes the laboratory facilities at the Center. These laboratories greatly enhance the potential scope and quality of the Federal Highway Administration research program by allowing inhouse studies of the fundamental aspects of chronic highway problems, special investigations and quick solutions for specific emergency problems, and the development of staff capabilities.

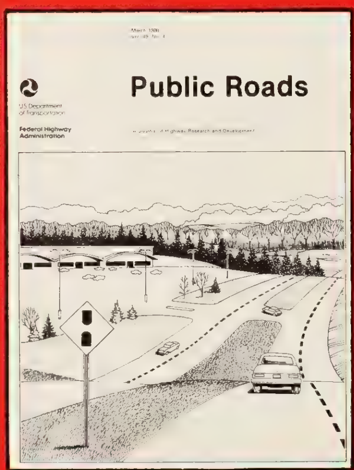
The brochure provides a brief description of the new laboratories in the Turner Building, the renovated laboratories in the Fairbank Building, and the outdoor testing facilities at the Center. The kind of research performed in the laboratories is described as well as the purpose of the research and innovative equipment used in gathering and processing data.

While supplies last, individual copies of the report and brochure are available without charge from the Federal Highway Administration, RD&T Report Center, HRD-11, 6300 Georgetown Pike, McLean, Virginia 22101-2296. (Telephone: 703-285-2144.)

TITLE SHEET, VOLUME 49







Public Roads

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT

VOLUME 49

U.S. Department of Transportation
Federal Highway Administration

June 1985–March 1986

This issue of *Public Roads* includes the title sheet for volume 49 (June 1985–March 1986). Including the title sheet in the March issue (and in future March issues for subsequent volumes) is a change from previous volumes when the title sheets were published as separate flyers and mailed at the same time as the June issue.

As with previous volumes, the title sheet chronologically lists article titles and alphabetically lists authors' names.

☆U.S. Government Printing Office: 1986—491-825/40002

Contents of Volume 49

List of Authors

(and volume page reference)

U.S. Department
of Transportation

**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

Official Business
Penalty for Private Use $300

Postage and Fees Paid
Federal Highway
Administration
DOT 512

U.S. MAIL

**SECOND CLASS
USPS 410-210**

in this issue

Investigation of Warning Signs for Median Crossovers

ITDS: A Data Base Driven Interface to Traffic Models Using a Microcomputer

Accident Analysis of Highway Narrow Bridge Sites