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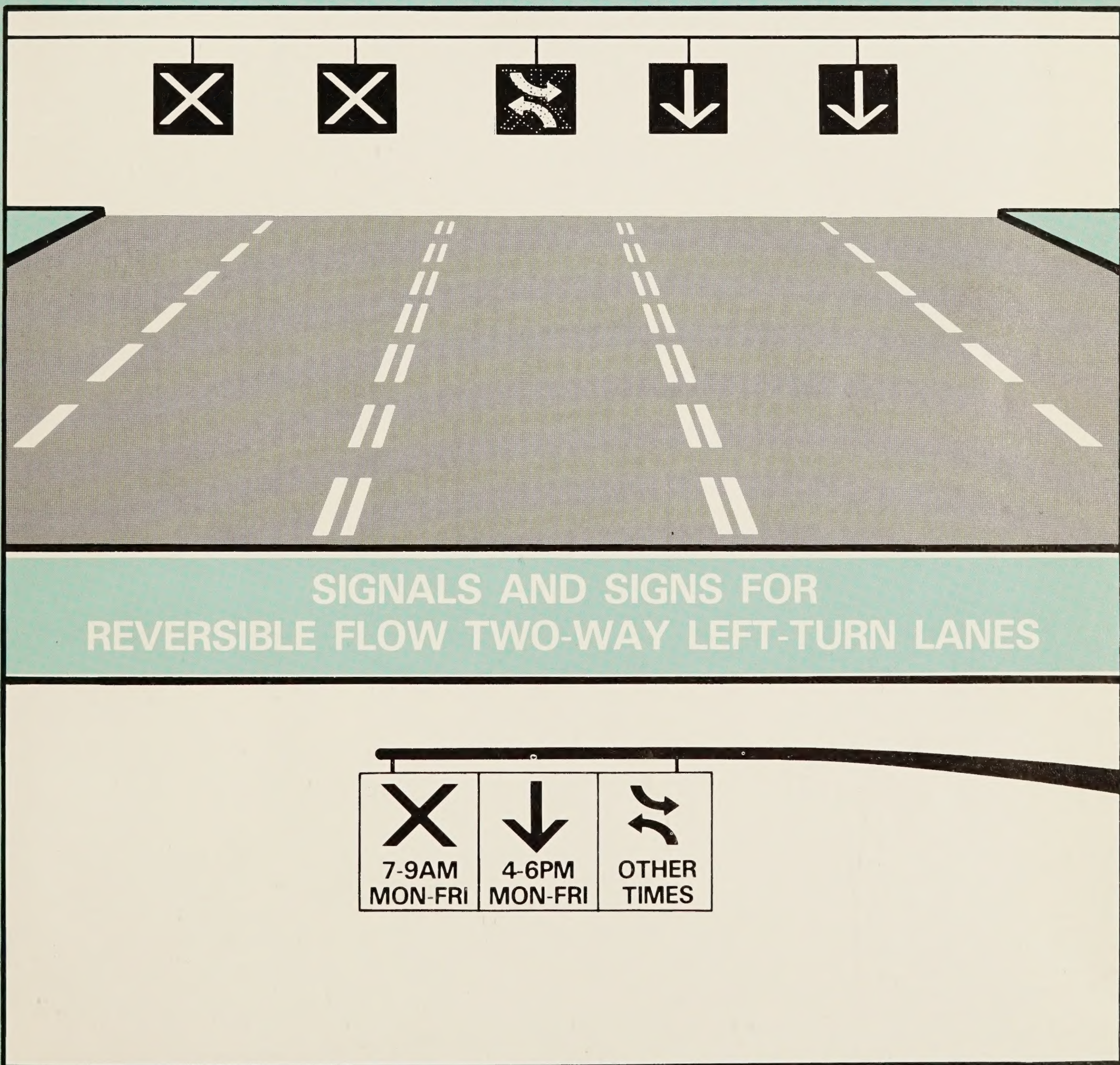

SIGNALS AND SIGNS FOR
REVERSIBLE FLOW TWO-WAY LEFT-TURN LANES

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

COVER: In the FHWA study discussed in the lead article, reversible flow two-way left-turn lane traffic controls were developed and tested in the laboratory. Shown are the recommended signals to indicate this control treatment, and, as an alternate, the recommended static sign.

IN THIS ISSUE

Articles

Departments

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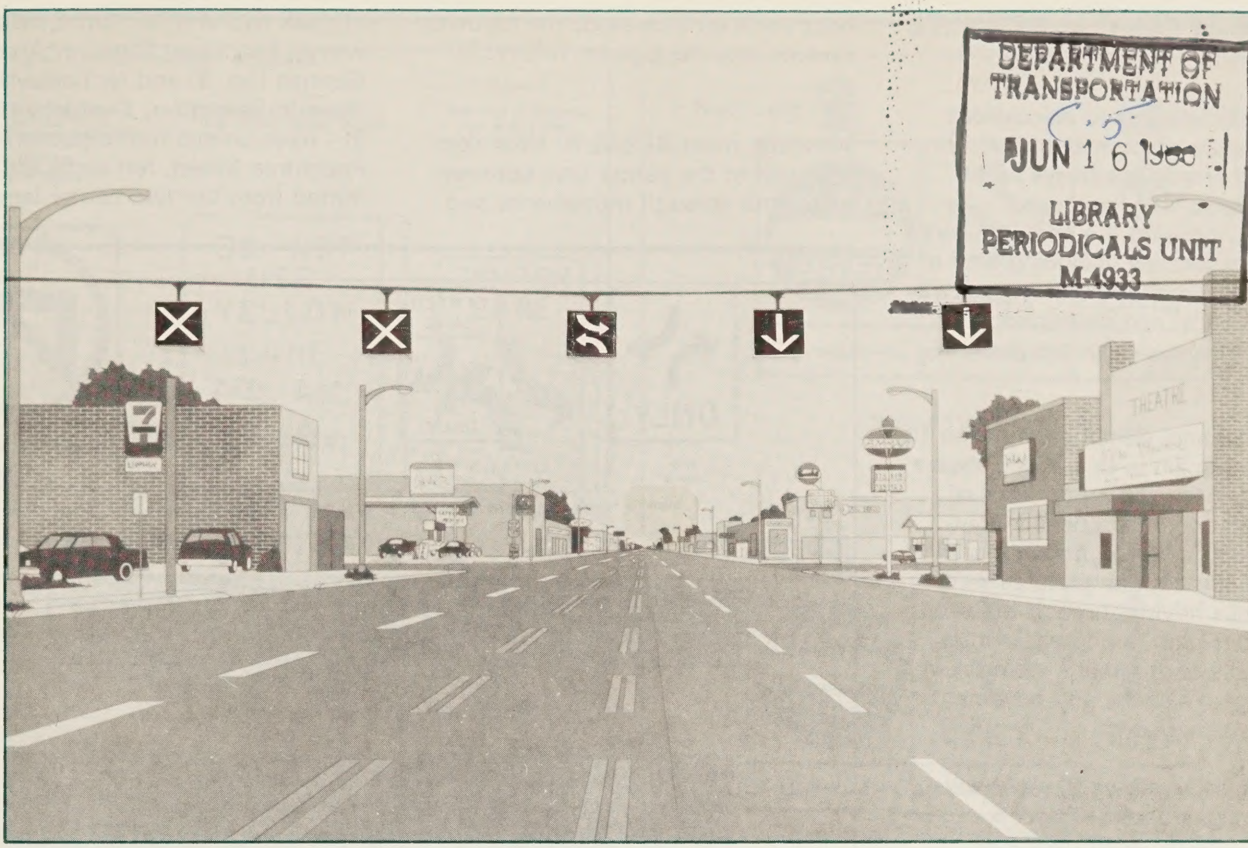

Traffic Control for Reversible Flow Two-Way Left-Turn Lanes

by
Merton Rosenbaum

Introduction

Traffic carrying capacity on existing roadways can be increased with reversible flow lanes and two-way left-turn lanes. Although these control treatments most frequently are used individually, some jurisdictions successfully alternate both treatments on the same arterial because of a combination of peak-period congestion and increased roadside development.

Traffic control devices for signing and marking a reversible lane and standards for signing and marking a two-way left-turn lane are included in the "Manual on Uniform Traffic Control Devices" (MUTCD) (fig. 1). (*1*)[1] No standards have been established for alternating the application of these two treatments on the same lane at different times of the day. MUTCD signals, signs, and markings have been adapted and augmented to meet specific site requirements and economic considerations. On a five-lane arterial, for example, the center lane may be reversed for inbound morning and outbound evening peak periods and used as a two-way left-turn lane during offpeak periods. However, the lack of standards has resulted in nonuniform treatments that can confuse drivers unfamiliar with the roadway.

In response to requests to develop traffic controls for the combination use of reversible flow and two-way left-turn lanes, the Federal Highway Administration (FHWA) sponsored a study in which past and present reversible flow two-way left-turn lane (RF2WLTL) sites were reviewed, driver information requirements were determined, and candidate RF2WLTL traffic controls were developed and tested in the laboratory. (*2*) This article discusses this study and the research results, which have been used by FHWA to propose changes to the MUTCD. (*3*)

[1] Italic numbers in parentheses identify references on page 10.

Review of Existing RF2WLTL Sites

A literature review and discussions with highway officials identified 19 undivided arterial roadways in the United States that have used RF2WLTL's during the past 25 years. Site characteristics, including kind of control, operational features, roadway characteristics, and descriptions of traffic control systems, are given in table 1.

The researchers visited each of the 15 sites that remain in operation, observing and photographing portions of each operational time period—outbound peak, offpeak, and inbound peak periods. Motion pictures were taken while driving through the sites in each direction during each time period. Still photographs were taken of the signs, signals, and pavement markings being used.

For example, in figure 2, overhead lane-use signs used in Phoenix, Arizona, include word messages giving the times of day for alternating the use of the center lane. The center lane is marked for two-way left turns. Figure 3 shows supplemental signs used in Phoenix to indicate left-turn restrictions and center lane use.

The Speedway Boulevard and Grant Road sites in Tucson, Arizona, use red and green flashing beacons to call attention to entrance and exit signs and to combination symbol and word message signs mounted over the center lane (figs. 4-6). Extensive roadside development and commercial signs competing for the driver's attention are typical of many arterials where reversible flow lanes and/or two-way left-turn lanes are used.

On Georgia Avenue in Montgomery County, Maryland, red X and green arrow signals indicate directional lane use (fig. 7). The outbound end of this site is an Interstate highway interchange. The typical clutter of commercial signs is present as well as frontage roads serving commercial establishments. Initially a raised median was removed to provide a two-way left-turn lane to serve roadside development. However, as peak-hour volumes increased, the roadway evolved into the present RF2WLTL site.

Although most RF2WLTL sites alternate use of the center lane between peak-hour through movements and offpeak two-way left turns, two roadways—Peachtree Street in Atlanta, Georgia (fig. 8) and Nicholasville Road in Lexington, Kentucky (fig. 9)—have unique traffic patterns. On Peachtree Street, left turns are permitted from the two center lanes

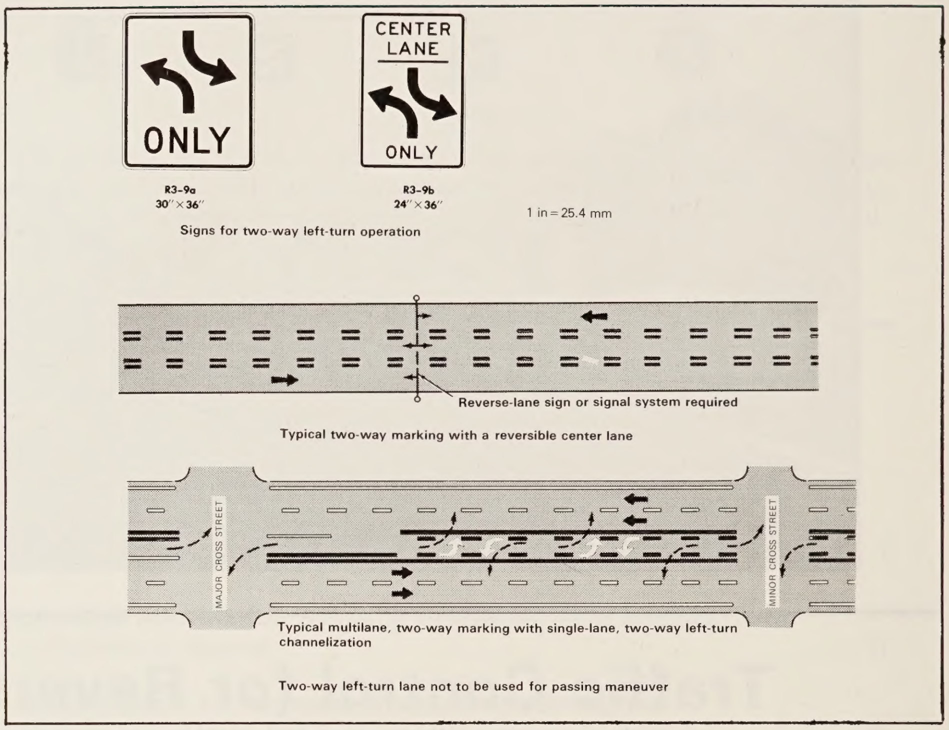

Figure 1.—Signs and pavement markings for two-way left-turn and reversible-lane operation used separately. (1)

Figure 2.—Overhead lane-use sign—Phoenix, AZ.

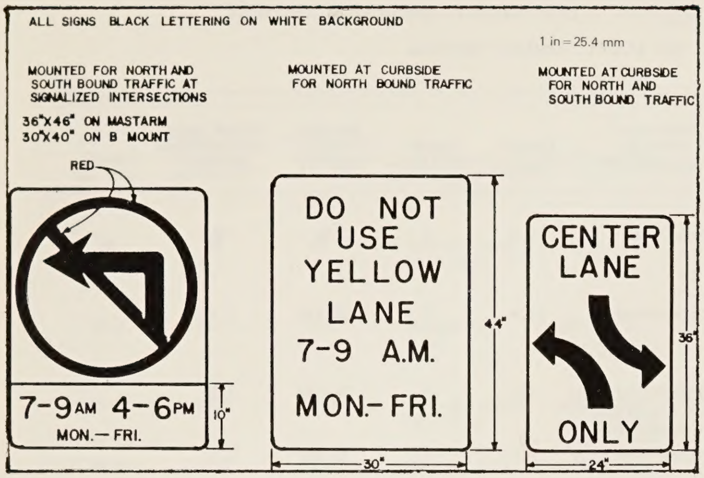

Figure 3. —Supplemental signs—Phoenix, AZ.

Figure 4. —Entrance signs—Tucson, AZ.

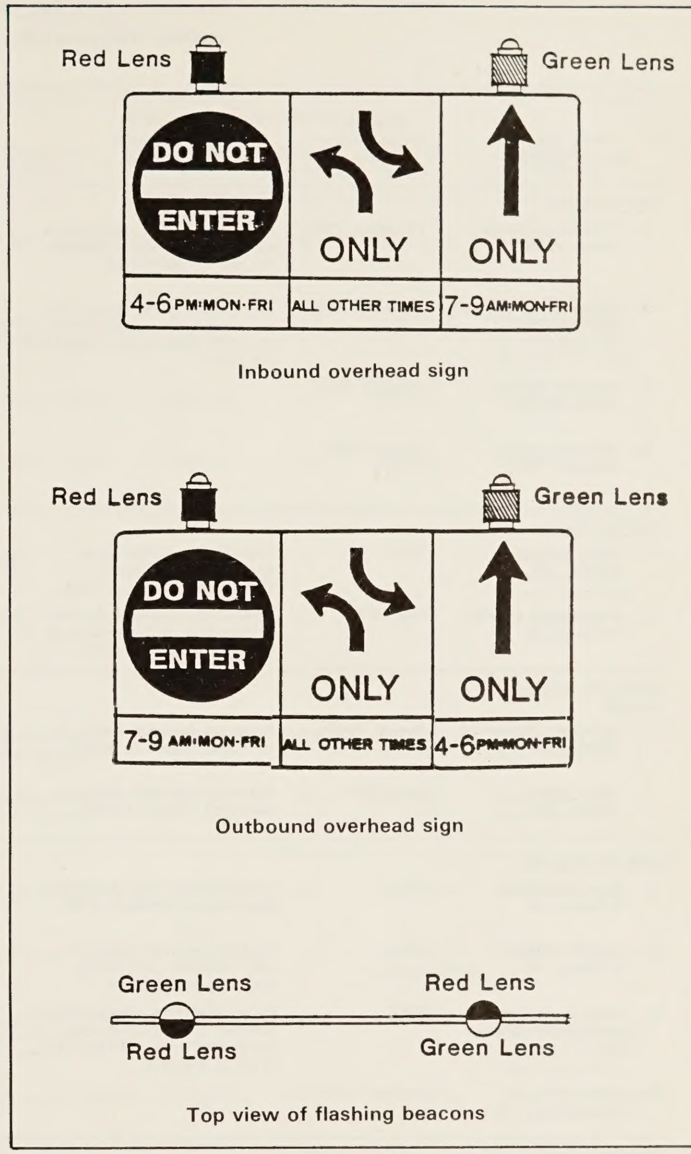

Figure 6. —Sign and flashing beacons— Tucson, AZ.

Figure 5. —Exit signs—Tucson, AZ.

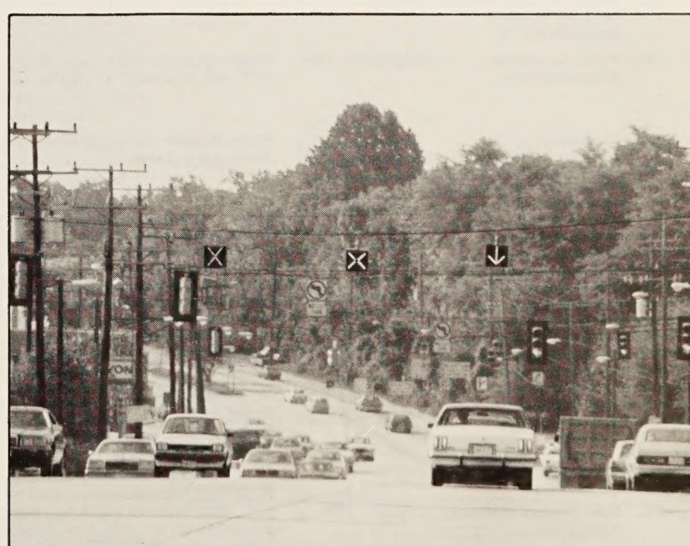

Figure 7. —Lane-use signals—Montgomery County, MD.

Table 1.--Summary of reversible flow two-way left-turn sites--control, operational features, roadway characteristics, and traffic control devices

Site and control system	RF2WLTL installation date	Modifications and remarks	Peak-hour left-turn restrictions	Length (miles)	Number of lanes	Average daily traffic	Signalized intersections per mile
Sign controls							
1. Fifteenth Avenue, Phoenix, AZ	December 1959	Reversible flow operations eliminated in 1974 because of safety problems.	None	1.4	3	NA	NA
2. Grand River Avenue, Detriot, MI	December 1959	Reversible flow operations permitted since May 1947. NO LEFT TURN signs installed in 1977.	Prohibited	12.4	7	25,930	5.2
3. Seventh Avenue, Phoenix, AZ	January 1979		Prohibited only at signalized intersections	6.0	6	30,000	2.2
4. Seventh Street, Phoenix, AZ	August 1982		Prohibited only at signalized intersections	8.0	6	35,000	2.5
Traffic cones							
5. Sixth Street, Tucson, AZ	1975	1.8-mi reversible flow section on east end installed in August 1968.	Prohibited	1.6	5	14,660	3.8
6. Washington Street, Phoenix, AZ	May 1978	Reversible flow operations eliminated in 1979 because of high manpower costs.	Prohibited at some minor intersections	2.3	6	NA	NA
Signs and flashing beacons							
7. Speedway Boulevard, Tucson, AZ	August 1980	Flashing beacons added on overhead signs in 1982.	Prohibited	3.7	5	36,320	3.2
8. Grant Road, Tucson, AZ	June 1981	Flashing beacons added on overhead signs in 1982.	Prohibited	4.6	5	39,520	2.6
Lane-use signals							
9. Memorial Drive, Atlanta, GA	1957	Incandescent matrix signals upgraded in January 1983.	None	1.2	3	13,000	5.0
10. DeKalb Avenue, Atlanta, GA	1959	Roadway reconstructed in 1981 because of transit system construction.	None	3.4	3	NA	NA
11. Georgia Avenue, Montgomery County, MD	1980	Three lane-use signal spans removed to reduce driver confusion with intersection traffic signals.	Prohibited	0.4	7	79,450	5.0
12. Route 202, Manchester, ME	October 1982		None	0.5	3	13,670	2.0
Lane-use signals and overhead signs							
13. Norman Bridge Road/ Decatur Street, Montgomery, AL	1962		Prohibited for minor intersections only	0.6	3	12,850	3.3
14. Michigan Avenue, Dearborn, MI	September 1963	Fiber optic signals used in 1977 and upgraded in 1979.	Prohibited	1.0	5	46,270	6.0
15. Broadway, Tucson, AZ	1973	Removed lane-use signals from outer lanes.	Prohibited	2.0	5	33,680	2.5
16. Red River Street Austin, TX	October 1973	Reversible flow operations eliminated in 1982 because of street reconstruction.	Prohibited for minor intersections only	1.3	3	12,240	2.5
Special applications							
17. Peachtree Street, Atlanta, GA	October 1975	Reversible flow operations permitted since 1966. Two-way left-turn lane maintained during peak periods only.	None	1.1	6	47,000	NA
18. Nicholasville Road, Lexington, KY	March 1979	Signs added to explain two-way left-turn lane and yellow X. Two-way left-turn lane maintained at all times.	None	2.6	5	35,130	3.8
19. N.W. Seventh Avenue, Miami, FL	January 1975	U.S. DOT demonstration project--reversible lane for buses only. Reversible bus lane removed in 1976.	Prohibited	2.5 4.8	7 5	19,420 18,210	NA

1 mi=1.6 km; 1 ft=0.305 m; 1 in=25.4 mm

Table 1.—Continued

Streets per mile	Commercial driveways per mile	Residential driveways per mile	Pavement markings	Post-mounted signs	Overhead lane-use controls: Kind of control	Size	Number per mile	Kind of support	Entrance/exit signing
NA	NA	NA	Two-way left-turn lane	NA	Static signs	3x9 ft	NA	Span wire	NA
25.2	35.0	0.2	Reversible lane	Left-turn restrictions	Series of three static signs	3x3 ft	6.0	Span wire	Overhead sign on western end of section only
20.3	45.2	15.5	Two-way left-turn lane	Left-turn and lane-use restrictions	Static signs	5x10 ft	4.0	Mastarm	Overhead sign
19.5	70.0	5.5	Two-way left-turn lane	Left-turn and lane-use restrictions	Static signs	5x10 ft	4.0	Mastarm	Overhead sign
28.1	32.5	10.0	Two-way left-turn lane	Left-turn and lane-use restrictions	None	—	—	—	Overhead sign on western end of section only
NA	NA	NA	NA	Barricades used to control traffic	None	—	—	—	Post-mounted sign
23.5	59.7	10.3	Two-way left-turn lane	Left-turn and lane-use restrictions	Static signs and beacons	4x9 ft	4.0	Mastarm	Overhead sign with beacons
19.1	86.7	17.2	Two-way left-turn lane	Left-turn and lane-use restrictions	Static signs and beacons	4x9 ft	4.0	Mastarm	Overhead sign with beacons
19.2	73.3	11.7	Reversible lane	None	Lane-use signals	24x30 in and 18x18 in	10.0	Span wire	Overhead signs
NA	NA	NA	Reversible lane	None	Lane-use signals	12x12 in	6.5	Span wire and mastarm	Overhead signs
22.5	60.0	0.0	Reversible lane	Left-turn restrictions	Lane-use signals over three center lanes	18x18 in	12.5	Span wire	Overhead lane control and post-mounted signs at entrance only
10.0	40.0	8.0	Two-way left-turn lane	Lane-use control	Lane-use signals	12x12 in	14.0	Span wire	Post-mounted sign at entrance only
28.3	36.7	45.0	Reversible lane	Left-turn restrictions	Lane-use signs; lane-use signals over center lane	12x12 in (signals)	11.7	Span wire	None
18.0	41.0	0.0	Reversible lane	Left-turn restrictions	Lane-use signals and variable message sign over center lane	18x24 in	7.0	Span wire	Post-mounted sign at entrance only
19.5	89.5	6.5	Two-way left-turn lane	Left-turn and lane-use restrictions	Lane use signals over three center lanes; variable message sign over center lane	12x12 in (signals)	8.0	Truss support	Overhead sign with beacons at entrance; without beacons at exit
NA	NA	NA	Reversible lane	Left-turn restrictions	Lane-use signals and variable message sign	NA	NA	Span wire	Static signs
NA	NA	NA	Reversible lane	None	Lane-use signals and variable message signs	24x24 in (signals); 30x42 in (signs)	10.0	Mastarm	Overhead signs at exit only
17.7	31.5	15.8	Reversible lane	Lane-use control	Lane-use signals	12x12 in	5.4	Span wire	None
NA	NA	NA	Painted left-turn channelization	NA	BUSES ONLY sign; lane-use signals over three lanes	NA	NA	Span wire	NA

during offpeak periods. During peak periods, the two center lanes alternate as two-way left-turn lanes. On Nicholasville Road, the center lane operates as a two-way left-turn lane during offpeak periods. However, during peak periods, only the one outside lane carries through traffic while the adjacent lane is used for two-way left turns.

Accident Analysis

Accident data furnished by officials of the jurisdictions visited included police accident reports, computer-generated accident files and summaries, and manually tabulated accident information. A comparative evaluation was conducted to determine if accident rates for the study sites were significantly different from rates for other urban highways where RF2WLTL's were not in use. Table 2 summarizes accident data from 11 of the RF2WLTL study sites and from 4 studies of urban sites. (*4–7*)

None of the average accident rates for the four urban sites differs significantly at the 0.05 level from the rate for the RF2WLTL sites. Overall, when using Kendall's combination test method (*8*), the average accident rates for RF2WLTL sites are not higher or lower at the 0.05 level than rates for other urban roadways with conventional two-way left-turn lanes.

Driver Information Requirements

Each of the existing RF2WLTL sites was reviewed to determine how well permissive and/or restrictive use information was being provided to the driver. An RF2WLTL site should provide applicable information before the section begins, at the entrance to the section, through the section, and at the end of the section. A worksheet was prepared detailing the lane configuration, delineation, signs, and signals used sequentially at each existing RF2WLTL site (fig. 10). Except on the through portion, few existing sites provide all needed driver information.

Preliminary Laboratory Experiment

A preliminary laboratory experiment was conducted to determine driver understanding of the abstract and contextual meaning of and preference for the symbols and markings being used at RF2WLTL sites. Thirty-two test subjects were shown slides of drawings of a five-lane suburban arterial with overlays of overhead symbols and lane delineation (see display art). The symbol meaning results are shown in table 3, and delineation meaning results are shown in table 4.

Figure 8.—Traffic patterns—Atlanta, GA.

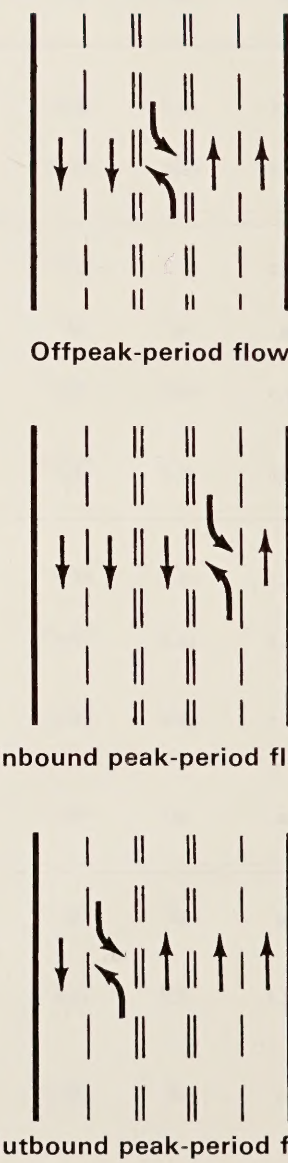

Figure 9.—Traffic patterns—Lexington, KY.

Table 2. — Comparison of accident rates (*4–7*)

Kind of control	Number of sites	Average accident rate[1]	Standard deviation	t-statistic[2]	p two-tail
Reversible flow two-way left-turn lane	11	9.4	4.0	–	–
Urban multilane undivided sites in 19 cities	2,496	8.6	10.8	0.65	0.53
Two-way left-turn sites:					
North Carolina	13	7.4	3.7	1.28	0.22
Texas	62	11.4	7.3	1.33	0.20
Virginia	17	6.3	4.3	1.90	0.07

[1] Accident rate = accidents per million vehicle miles.
[2] t-test results obtained by comparing the reversible flow two-way left-turn site with the other control types for $p > 0.05$.

1 mi = 1.6 km

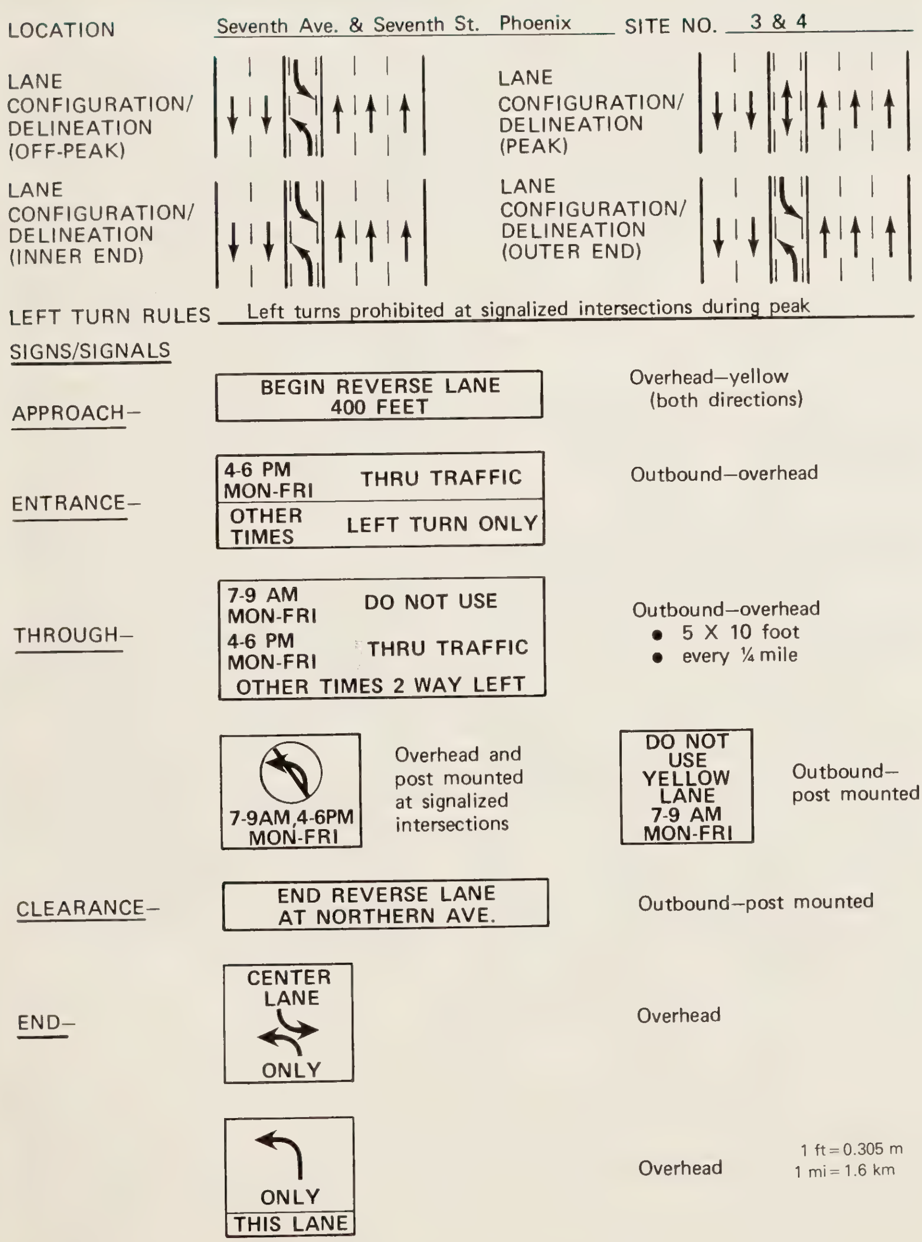

Figure 10. — Example of RF2WLTL facility information worksheet.

All of the test subjects understood the meaning of permissive green arrows and restrictive red X's. However, no subject identified the yellow X as meaning a left-turn lane. The two-way left-turn arrows were identified by 38 percent (when steady) and by 41 percent (when flashing) as a left-turn symbol. Clearly, the two-way left-turn arrows have the best inherent meaning. The delineation test results indicated that subjects understood the reversible flow lane markings better than the other markings presented. The overhead signal symbols were tested in relation to lane position. The two-way left-turn arrows were found to be much more effective than the yellow X in indicating a two-way left-turn lane (table 5).

After the meaning tests were completed, the operation of the RF2WLTL was explained to the subjects. A preference test was administered. Subjects preferred the two-way left-turn arrows 10 to 1 over the yellow X as a symbol for two-way left turns.

Table 3.—Symbol meaning test results—percent subject responses

Response to "What does this lane control signal mean?"	Green ↓ Steady	Green ↓ Flashing	Red X Steady	Red X Flashing	Yellow ↓ Steady	Yellow ↓ Flashing	Yellow X Steady	Yellow X Flashing	White Steady	White Flashing
	Lane control signal									
Do not use this lane			100	100			84	87	3	6
Use this lane for through travel	100	100			81	84				
Use this lane for left turns									38	41
Use this lane for right turns										
Don't know					19	16	16	13	59	53
Total	100	100	100	100	100	100	100	100	100	100

Table 4.--Roadway marking test--percent subject responses

QUESTION	Lane Marking / Response					
Which lanes may have traffic traveling toward you?	Yes	100	100			
	No			100	100	100
	Don't know					
Which lane may you turn left from?	Yes			100		
	No	100	100		100	100
	Don't know					

QUESTION	Lane Marking / Response					
Which lanes may have traffic traveling toward you?	Yes	100	94	34		
	No		3	31	97	100
	Don't know		3	34	3	
Which lane may you turn left from?	Yes		9	69	22	
	No	100	88	12	72	100
	Don't know		3	19	6	

QUESTION	Lane Marking / Response					
Which lanes may have traffic traveling toward you?	Yes	100	100	41		
	No			31	100	100
	Don't know			28		
Which lanes may you turn left from?	Yes		3	41	50	
	No	100	91	41	44	100
	Don't know		6	18	6	

Detailed Laboratory Experiment

Using the results of the driver information requirements analysis and the preliminary laboratory tests, six candidate traffic control systems were developed for detailed laboratory evaluation (fig. 11). Eighteen slides were prepared—three for each of the six systems—displaying the morning inbound peak, the afternoon inbound peak, and the offpeak traffic control conditions. These slides were shown to test subjects as overlays on a drawing of a five-lane suburban arterial with reversible flow pavement markings (see display art).

Seventy-four subjects, in 6 groups of 11 to 14, were shown the 18 slides. The order of presentation was randomized among the six groups. To simulate driving, the subjects selected on an answer sheet lane usage as depicted on each slide. As in the preliminary laboratory tests, the operation of the RF2WLTL was not explained initially. Following the tests, the operation of the RF2WLTL was explained and a preference test conducted using a three-page answer sheet, one page for each time period (fig. 12).

Table 5.--Symbol meaning in relation to lane position--percent subject responses

QUESTION	Which lanes may have traffic traveling toward you?					Which lane may you turn left from?				
Signal / Response	Red X	Red X	Red X	Green ↓	Green ↓	Red X	Red X	Red X	Green ↓	Green ↓
Yes	100	100	100						94	
No				100	100	100	97	97		100
Don't know							3	3	6	
Signal / Response			Green ↓					Green ↓		
Yes	100	100	6					97		
No			94	100	100	97	97		97	97
Don't know						3	3	3	3	3
Signal / Response			Yellow X					Yellow X		
Yes	100	100	59				3	3	66	
No			3	100	100	100	97	50	15	100
Don't know			38					47	19	
Signal / Response			Yellow ↓					Yellow ↓		
Yes	100	100	3					75	13	
No			78	100	100	100	100	0	81	100
Don't know			19					25	6	
Signal / Response			Yellow X flash					Yellow X flash		
Yes	100	100	59					28	44	
No			16	100	100	100	100	31	34	100
Don't know			25					41	22	
Signal / Response			⇅					⇅		
Yes	100	100	41					81	13	
No			9	100	100	100	100	3	81	100
Don't know			50					16	6	
Signal / Response			⇅ only					⇅ only		
Yes	100	100	59					88	12	
No			6	100	100	100	100	0	88	100
Don't know			34					12	0	

Results

Correct responses to all of the questions on the candidate systems were combined with preference corroboration and aggregated as follows:

Candidate system	Percent correct responses
I	77
II	83
III	57
IV	56
V	58
VI	63

Candidate II, the system including the flashing two-way left-turn arrow symbol, was shown to be better than all other candidates. Candidates III, IV, V, and VI were essentially equal. An examination by time period of candidate I data showed the yellow X to be a very poor indicator of the correct lane for left turns. Also, the yellow X was found to be confusing when used to designate two-way left-turn lanes during the offpeak period. However, the two-way left-turn arrows were easily understood.

FHWA's Office of Traffic Operations' review of the completed RF2WLTL research (*2*) resulted in proposed MUTCD amendments being published in the "Federal Register" dated March 13, 1985. (*3*) The proposed amendments are summarized as follows:

- Add a new section to provide a static sign system as an acceptable alternate to the preferred (but more costly) lane-use control signals. The sign selected was candidate IV (fig. 11), omitting the word "ALL" from the offpeak section of the sign.
- Require double broken yellow pavement markings on each side of a reversible flow two-way left-turn lane.
- Replace the flashing yellow X signal with the nonflashing symbolic two-way left-turn arrow signal (as shown in fig. 11, candidate II) for two-way left-turn operation. Use a single left-turn arrow signal for one-way left-turn lanes.

Comments on the proposed amendments were received in July 1985 and are under consideration by advisory FHWA organizations.

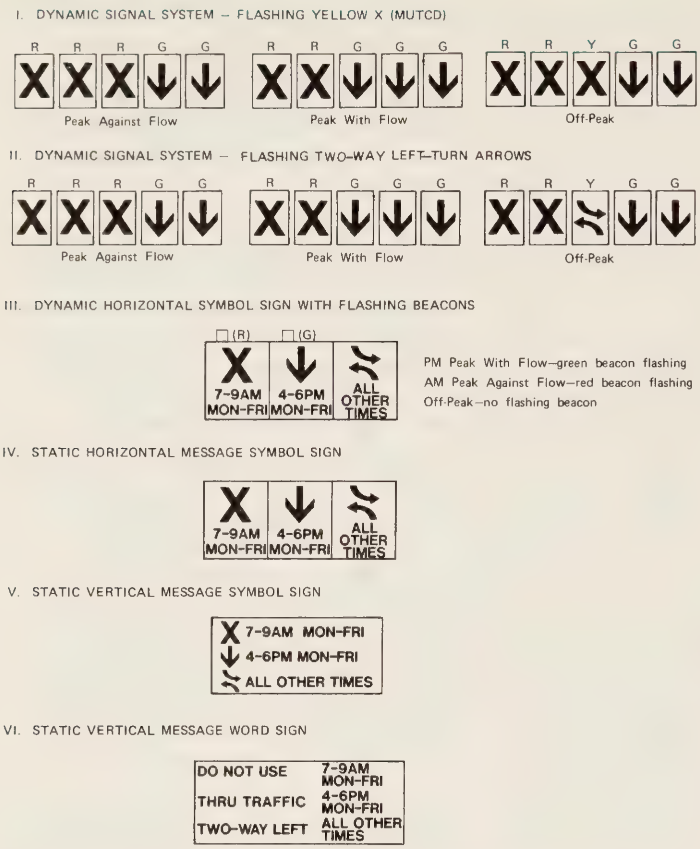

Figure 11.—Candidate RF2WLTL traffic controls developed for detailed laboratory tests.

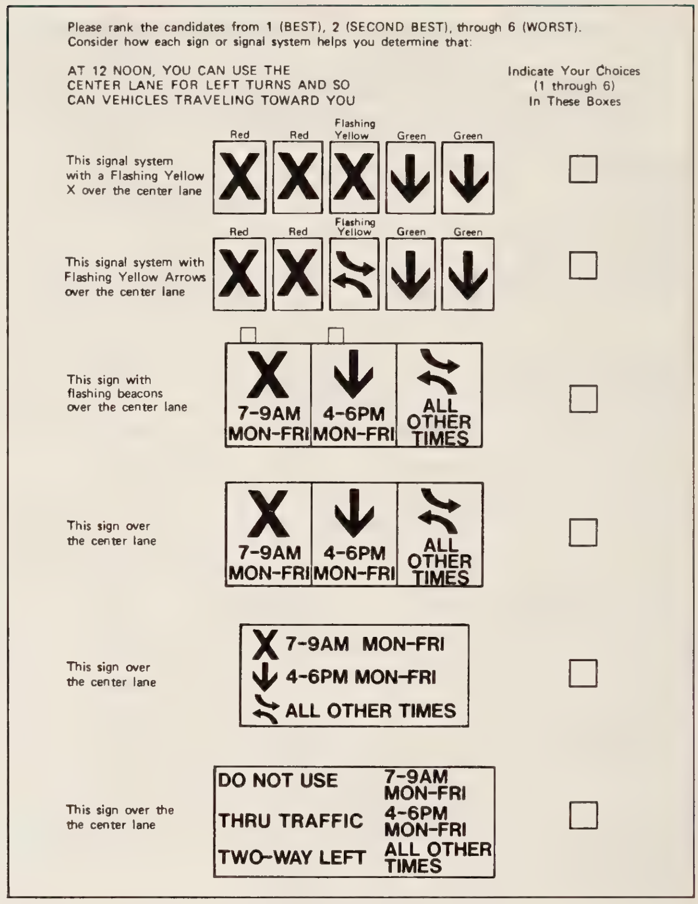

Figure 12.—Example of preference test answer sheet.

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(*1*) "Manual on Uniform Traffic Control Devices," *Federal Highway Administration,* Washington, DC, 1978.

(*2*) R.L. Knoblauch, M.R. Parker, Jr., K.H. Tsuchiyama, and J.C. Keegel, "Traffic Control for Reversible Flow Two-Way Left-Turn Lanes," Final Report No. FHWA/RD-85/009 and State-of-the-Art Report No. FHWA/RD-85/010, *Federal Highway Administration,* Washington, DC, October 1984. (Stock Nos. PB 85 129674 and 85 198687.)[2]

(*3*) "Federal Register," vol. 50, No. 49, Wednesday, Mar. 13, 1985, Washington, DC.

(*4*) T.K. Datta, M.R. Parker, Jr., and D.A. Randolph, "Analysis of Urban Arterial Road and Street Accident Experience," Report No. FHWA/RD-82/137, *Federal Highway Administration,* Washington, DC, September 1982. (Stock No. PB 85 184448.)

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

[2]Reports with PB numbers may be purchased from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

Integrated Information Systems for Better Data Management

by
Richard A. Richter

Data Needs of Highway and Safety Program Administrators

A highway administrator reads a newspaper headline of a recent traffic accident—TWO KILLED AS CAR HITS BARRIER. The story establishes that the barrier end speared the vehicle and that the driver had been drinking. The administrator wonders, "Who's responsible? The State Police, those involved with the DWI (Driving While Intoxicated) program, or me? Maybe the barrier was poorly maintained or designed. Is the same thing happening frequently throughout the State?"

Responding to the question of responsibility in traffic incidents of this kind is not an unusual task for a highway or safety program administrator. The responses an administrator makes in such cases depend heavily on data gathered by a State and stored in files. To have ready access to these data, an administrator needs an efficient information management system incorporating data collected from many sources and for many purposes. The system needs to be comprehensive, provide quick access to particular aspects of the problem, and provide interrelationships such as rates and trends. However, the more comprehensive the systems are, the more branches, departments, or even agencies within a State that become involved, complicating system maintenance and operation.

In addition, some of the basic requirements for any information system—a common reference system, the ability to screen nonessential information, the ability to be updated easily at regular intervals, and immediate accessibility to users—are difficult to achieve with large, comprehensive information systems using data from several agencies. Therefore, smaller, agency-specific information management systems have been the trend, particularly for highway-related safety information. However, these systems may not be capable of satisfying all needs.

Current State Highway Data Systems

With the emergence of large mainframe computers in the 1960's, many State highway agencies tried to develop efficient, integrated data systems that would serve internal needs as well as respond to outside data inquiries. These efforts generally failed; the cost and personnel required of each group within a highway agency to service an integrated data system were greater than that required to maintain less comprehensive but adequate individual data systems.

The advent of the microcomputer further promoted the concept of individual data systems by facilitating system maintenance and expansion, decreasing data acquisition turnaround time, and allowing administrative control over the files within the individual interest group. Separate individual data systems commonly were developed for financial, accident, maintenance, and traffic control information; roadway features, bridge, and skid inventories; traffic volume counts; and preconstruction engineering management. Although many of these systems used similar reference systems, the reference systems usually were selected to facilitate data input for the particular subject of interest and therefore were not readily interconnected as they would be in an integrated information system.

As useful as the individual data systems are, they do not allow administrators to make full use of their existing files. Every decision highway administrators make can benefit by ready access to composite records maintained on the various highway systems. For example, a pavement's condition from year to year influences the design of new pavements. Also, data on features at roadway facilities with recurring accidents can be used to establish a pattern of accident cause and to select countermeasures. Finally, the results from guardrail-related accidents can identify the kinds of barriers that may require more frequent replacement. All of these decisions require data from more than one file, frequently accessed by more than one variable, to show trends, rate, severity, or related features. The answer then appears to be an integrated information system (fig. 1).

Such a system typically is accessed through a computer-based management program that uses data from several sources and treats the data as if coming from a single file. These data are linked through a common highway location reference system, usually based on mile points.

Typically all data collected in States are related to some sort of a reference system, the common reference being the number of miles from an easily identified point, milepost, or physical feature on the highway system. It is not always convenient, however, for all data collectors to start measuring from the same point or, in some cases, even use a mile-point system. For example, they may find it more convenient to collect data by relating it to roadway sections of various lengths. Converting all roadway, traffic, and accident files to a common reference system is not easy, but it is a key first step in establishing an integrated information system. (*1*)[1] Then, existing individual data systems may be tied into such a data base management program to upgrade current data accessibility and expand an agency's information system.

Currently, several States have or are developing integrated highway information systems. North Carolina has a system that allows local municipalities to access Statewide files of accidents, roadway features, and traffic characteristics. Utah integrates accident, geographic, and highway information files through a data base management system and allows data access at three levels of detail—executive/manager, technician, and data processing personnel (fig. 2). Idaho and Kansas currently are integrating highway data in cooperation with the Federal Highway Administration (FHWA).

To determine the status of existing State information systems and the degree to which individual files now have been integrated within major systems, the National Cooperative Highway Research Program under its Project 20-5 is developing a synthesis report, "Integrated Highway Information Systems."

Uses of Integrated Data Information Systems

An integrated information system within a highway agency can allow file data to be accessed by roadway features or by location. Often, a highway agency administrator would like to know the number of accidents at luminaire poles, bridge ends, or sign supports and similar roadway features rather than, for example, just knowing which locations are having a particular number of accidents.

A highway agency's information system also can be used to develop accident rates for various roadway features. Raw numbers of accidents at a particular location mean very little unless they are considered in relation to the traffic volumes or some other measure of exposure. An integrated information system can draw upon traffic, accident, and roadway feature data and store them in a single file. Accident rates for a specific feature then can be developed easily by straightforward computer calculations. Examples of data that can be developed are accident rates at all bridge ends, accident rates on roadways with shoulders of a specified width, or accident rates on roadways with a designated skid number.

Another feature of an integrated information system is the ability to specify particular data levels in the output—for example, fatal accidents on all bridges with an average daily traffic (ADT) volume less than 1,000 vehicles per day and having roadway widths of 22 ft (6.7 m) or less. By controlling data variables and determining their interrelationships, the highway administrator can determine how highway improvements are changing accident patterns and can rank accident countermeasures by cost-effectiveness.

Even without all of the agency's files or all related safety information, a highway agency's integrated information system can help in evaluating the safety effectiveness of highway improvements. Ideally, accident countermeasure effectiveness is determined by comparing an improved site with a similar but unimproved control site. It is difficult to locate two sites identical in geometrics, traffic, and hazardousness without using an integrated information system. With an integrated information system, however, the characteristics of the improved site can be described and a file search can be conducted on the basis of these characteristics. Even if a control site cannot be located, the average accident rate from a composite group of similar sites will provide a valid basis for comparison.

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[1]Italic numbers in parentheses identify references on page 14.

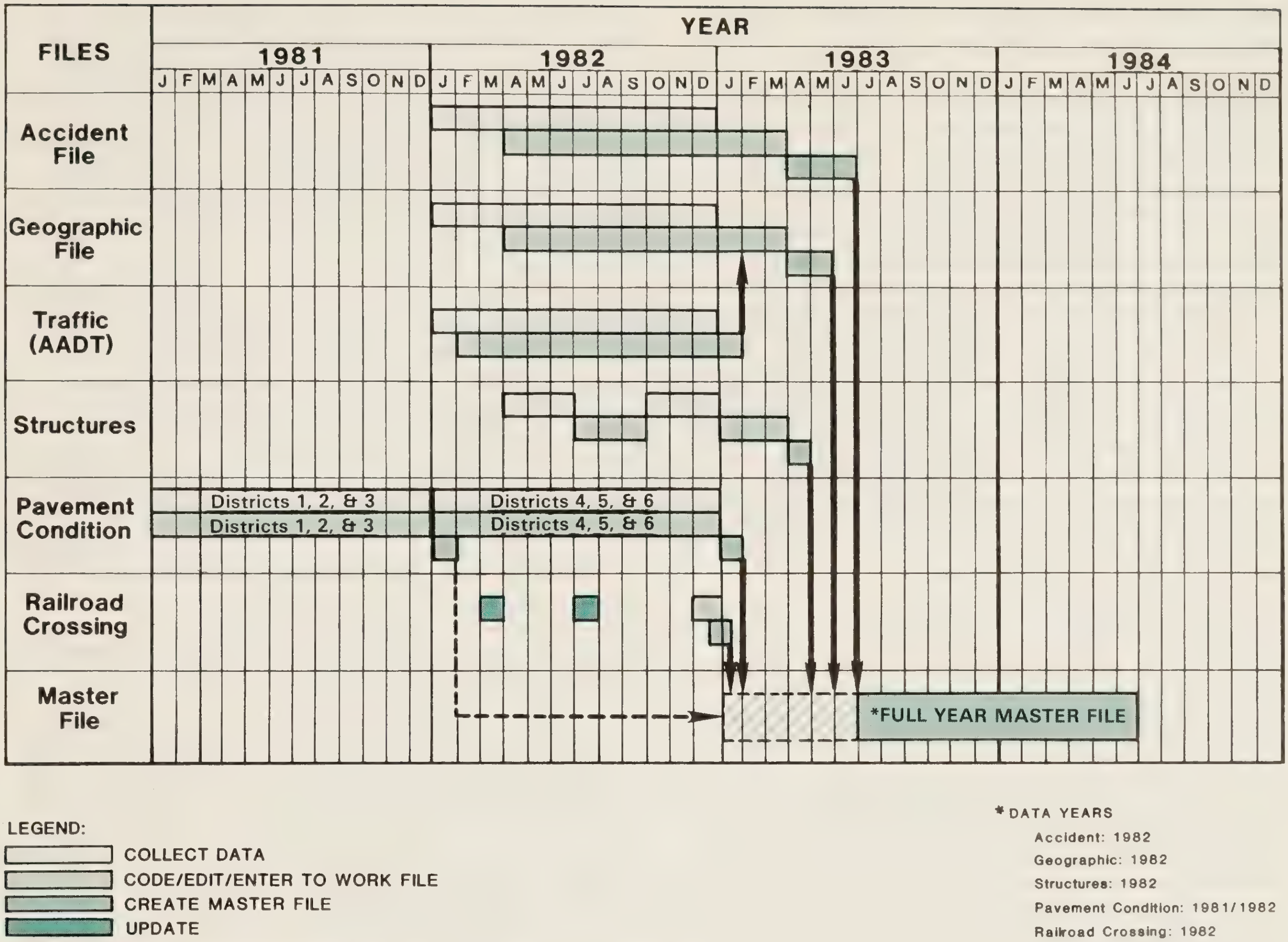

Figure 1.—Integrated information system data collection and file development cycle.

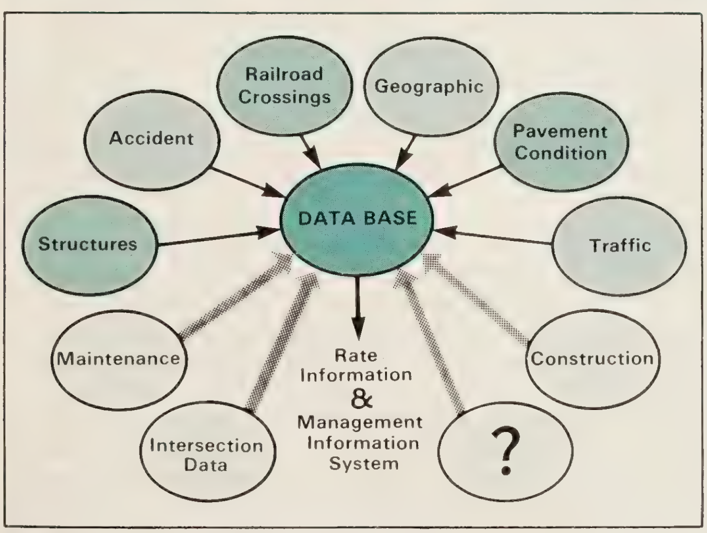

Figure 2.—Utah's integrated information system.

Another useful feature of an integrated information system is that it permits the depth of detail to be varied. Not all file users have a need for the same depth and detail of information. For example, if an administrator wants to know about accidents that occur at bridge ends on a particular highway route, the file system can sort through data on all accidents that occur in the State with related details and select the bridge end accidents. With an integrated file system, the user can have the computer select the route, the locations (bridge ends), the number of accidents, the bridge width, the approach width, whether or not the approach guardrail is connected to the bridge rail, and other pertinent details.

An integrated file system also can be used to monitor the effectiveness of a particular program such as upgrading with a new kind of barrier terminal. For example, an integrated file report can be programmed to search the entire State system for barrier terminals and print, on a monthly basis, the locations, the accident experience, the roadway widths, the prevailing traffic volumes, speed, and other related factors.

Large-Scale, Comprehensive Computerized Safety Information Systems

Data needs for solving highway safety problems are not satisfied by highway data alone but require information such as driver and vehicle registration, enforcement records, court records, and driver training. This introduces the need for common reference system links other than highway mile points. Levels of enforcement, accident history of drivers, relative skills of drivers, or reliability of vehicles are examples of the many variables that contribute to accidents but that usually cannot be associated with a particular point on the highway system.

Common reference links may be accidents, specific safety programs, or kinds of driver violations. Each link has its limitations. Accidents, for example, are temporary conditions, and data must be recorded before items of interest change or disappear. Also, specific safety programs can vary in scope. Finally, violations can vary as regulations are enforced at different levels.

The need for a comprehensive data system for managing traffic safety programs was recognized by the U.S. Congress in 1984. Public Law 98-363 called for the establishment or improvement of Comprehensive Computerized Safety Recordkeeping Systems (CCSRS) in each State. The nature of such systems was discussed at a Transportation Research Board workshop held in Airlie, Virginia, May 6-8, 1985. (*2*) Nine principal applications were considered as being served by a CCSRS—identification of high-accident locations, identification of hazardous roadway elements, development of accident surrogates, selective traffic law enforcement, traffic enforcement planning, driver improvement programs, monitoring of court proceedings, monitoring designated truck routes, and evaluation of highway safety projects and programs. The States of Washington and Texas currently are planning large CCSRS's. As current activities of the National Highway Traffic Safety Administration and the Transportation Research Board develop, new insights into highway safety data management can be expected.

The need for large-scale, comprehensive information systems that integrate all highway safety data is apparent, even though there is much value and more immediate application in managing data for many uses through an intermediate-level integrated system. The potential applications and uses of data from integrated information systems, whether large-scale or intermediate-scale, are unlimited.

Looking Ahead

FHWA's Offices of Research, Development, and Technology are supporting both ongoing contracts and planned activities with State highway agencies to develop greater data management capabilities. FHWA expects that transferring state-of-the-art computerized file system technology to States not presently using such technology can save funds through better, more informed management decisions.

The collection of traffic volume data, feature inventories, and roadway conditions is very expensive, yet necessary, because cost-savings with an integrated file system are through the data interrelationships it provides—interrelationships that are needed to make sound management decisions. For example, the State of Utah estimated the cost of a Statewide analysis on pavement rutting at $160,000. Because of the availability of an integrated file system that could interrelate pavement surface information, traffic accidents, and traffic volumes, Utah completed the study on pavement rutting for approximately $18,000.[2]

Although many of the problems experienced by States in developing comprehensive integrated file systems are institutional rather than technical, firsthand information about operating systems, the configurations of those systems, and the solutions developed for common technical problems can assist interested States. To facilitate dissemination of this information as well as to address the expected institutional difficulties, FHWA is planning a series of workshops on expanding file systems through linkage. These workshops will include discussions of the differences among State highway agency file systems and develop some common treatments and procedures for assisting States in overcoming institutional roadblocks and in understanding the required computer software and hardware.

This article has attempted to put into perspective the integrated and individual levels of computerized information management systems, identify the potential the systems have for those not familiar with such systems, and suggest to States a willingness by FHWA to assist States with the file system technology needed to update their file systems. Top level support from highway agency management is needed to make such comprehensive highway information systems a reality.

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Accident Costs for Highway Safety Decisionmaking

by
Brenda C. Kragh, Ted R. Miller, and Kenneth A. Reinert

Introduction

Important advances are occurring in the field of accident costs. In these budget-conscious days of less money available to decrease the hazards resulting from our fast-paced, mobile society, it is increasingly important to spend available money on the most useful safety measures. To choose the best safety measures, the common denominator—the dollar—is used to compare the costs to implement a safety measure with the expected benefit. Because the highway community uses the number of accidents eliminated or made less severe by a countermeasure as the yardstick for benefits, the dollar amount placed on different kinds of accidents is crucial in spending tax dollars wisely. Highway professionals are no longer satisfied with accepting accident cost numbers routinely updated from an obsolete or undocumented methodology and published as a principal source of information.

Today, few engineers or even economists who specialize in accident costs agree on both the components of accident costs and how to collect the pieces of information. Because of this, in 1982 the Office of Safety and Traffic Operations Research and Development in the Federal Highway Administration's (FHWA) Offices of Research, Development, and Technology initiated research to review and study the basis of accident costs. (*1*)[1] The objectives of the study were to review the differing accident cost numbers and methodological approaches used and to develop, present, and explain updated accident cost numbers. Also, several of the more popularly used accident cost numbers were converted to a common base year (1980) for comparative purposes.

This article describes the results of the FHWA study and suggests accident costs for use by the States and others in determining how best to spend tax dollars to get the most from our highway safety program. Also discussed are the components of accident costs and some factors that influence how the numbers are determined.

[1]Italic numbers in parentheses identify references on page 20.

Accident Classifications

Valuing accident costs in dollars requires some measure of accident severity. Some States keep only simple records, classifying accidents into fatal, serious injury, and minor injury. In the highway community, motor vehicle accidents traditionally have been classified as fatal; A, B, or C injury; or property damage only (PDO) (table 1). (*2*) The American Association for Automotive Medicine developed a more definitive way to classify accidents—the Maximum Abbreviated Injury Scale (MAIS) (table 2). (*1*) This scale is used by a few States and by the U.S. Department of Transportation, which uses the traditional A-B-C classification system as well.

Table 1.—A-B-C injury classification (*2*)

Code	Injury severity level	Representative injuries
F-type	Fatal injury:	A fatal injury is any injury that results in death (within 90 days of occurrence).
A-type	Incapacitating injury:	An incapacitating injury is any injury, other than a fatal injury, which prevents the injured person from walking, driving, or normally continuing the activities (s)he was capable of performing before the injury occurred.
	Inclusions:	Severe lacerations, broken or distorted limbs, skull or chest injuries, abdominal injuries, unconscious at or when taken from the accident scene; unable to leave accident scene without assistance. And others.
	Exclusions:	Momentary unconsciousness. And others.
B-type	Nonincapacitating evident injury:	A nonincapacitating evident injury is any injury, other than a fatal injury or an incapacitating injury, which is evident to observers at the scene of the accident in which the injury occurred.
	Inclusions:	Lump on head, abrasions, bruises, minor lacerations. And others.
	Exclusions:	Limping (the injury cannot be seen). And others.
C-type	Possible injury:	A possible injury is any injury reported or claimed which is not a fatal injury, incapacitating injury, or nonincapacitating evident injury.
	Inclusions:	Momentary unconsciousness, claim of injuries not evident, limping, complaint of pain, nausea, hysteria. And others.
PDO-type	Damage:	Damage is harm to property that reduces the monetary value of that property.
	Inclusions:	Harm to wild animals, or birds, which have monetary value. And others.
	Exclusions:	Harm to wild animals, or birds, which have no monetary value; harm to a snowbank unless, for example, additional snow removal costs are incurred because of the harm; mechanical failure during normal operation, such as tire blowout, broken fan belt, or broken axle. And others.

Components of Accident Costs

Most experts agree that accident costs are composed of direct costs and indirect costs, but there is little agreement as to what constitutes these two costs, particularly the indirect costs.

Direct accident costs

Direct accident costs are the costs of goods and services produced and consumed as a result of accidents. Examples of direct costs cited in the FHWA study were as follows:

- Property damage.
- Emergency medical and transportation service costs.
- Medical treatment costs—emergency room, hospitalization, doctor/surgeon, follow-on care, home modification, etc.
- Legal and court costs.

These costs and others are added together as one portion of accident costs.

Indirect accident costs

Indirect accident costs value all changes and irretrievable losses experienced by people involved in accidents and by society. These changes include intangible aspects of life such as pain and suffering, tangible items such as administrative work performed by service-oriented institutions, or the cost of goods and services the individual(s) now will not be able to produce or perform because of the accident.

The following four indirect cost categories were cited in the FHWA study:

- Social mechanism.
- Human capital.
- Psychosocial deterioration.
- Value of life and safety.

Social mechanism costs

Social mechanism costs stem from the multitude of work and paperwork generated when a person dies or is injured in a motor vehicle accident. The costs for personnel in police and fire departments; insurance, welfare, and public assistance agencies; highway departments; coroners' offices; and others to complete and process forms and perform other tasks after an accident occurs become significant when all accidents are considered. However, these costs are not easily determined. Each agency mentioned above is responsible for more than just actions related to motor vehicle accidents. Thus,

Table 2. — Maximum Abbreviated Injury Scale (*1*)

AIS code	Injury severity level	Representative injuries
1	Minor injury	Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness (no other neurological signs).
2	Moderate injury	Major abrasion or laceration of skin; cerebral concussion (unconscious less than 15 minutes); finger or toe crush/amputation; closed pelvic fracture with or without dislocation.
3	Serious injury	Major nerve laceration; multiple rib fracture (but without flail chest); abdominal organ contusion; hand, foot, or arm crush/amputation.
4	Severe injury	Spleen rupture; leg crush; chestwall perforation; cerebral concussion with other neurological signs (unconscious less than 24 hours).
5	Critical injury	Spinal cord injury (with cord transection); extensive second- or third-degree burns; cerebral concussion with severe neurological signs (unconscious more than 24 hours).
6	Maximum injury (currently untreatable, immediately fatal)	Decapitation; torso transection; massively crushed chest.

determining how much time and expense each agency devotes solely to motor vehicle accidents is difficult. In the FHWA study, social mechanism costs were estimated for police, fire department, and coroner/medical examiner services; insurance administration; and welfare and public assistance administration. However, State motor vehicle agency administration and State and local highway department costs could not be satisfactorily estimated with the available data.

Human capital costs

Human capital costs reflect the work the injured or dead person can no longer perform either in the short- or long-term. This work could be for an employer, the family, or for society in general. Duties outside the workplace, such as household chores and volunteer activities, also may be affected. Human capital costs also include reduced abilities to work. For example, a surgeon whose manual dexterity is affected by a motor vehicle accident still can be a doctor in another capacity—just not a surgeon. Consequently, the surgeon's earnings may be reduced.

Psychosocial deterioration

Psychosocial deterioration evaluates changes in the quality of life that are overlooked in the human capital cost category. Intangible items such as mental anguish or chronic pain; family and marital erosion; drug/alcohol abuse; juvenile delinquency; missed/delayed education; overall reduction in quality of life; and loss of contact with friends, family, and community are harder to express in dollar values than are the wages used to value some aspects of human capital costs. However, this fact does not diminish the importance of these intangible items.

Value of life and safety

The value individuals place on their life and safety reflects their willingness to pay (in money, time, freedom, or some other measure of value) to reduce the number or severity of accidents or to ensure continued health and safety.

The many methods for determining willingness-to-pay accident cost numbers or values attempt to determine the dollar value the public is willing to pay to make small changes in the probability of an accident occurring. Such numbers have human capital and psychosocial costs incorporated because each person's responses and actions would be guided to some extent by expected income and quality of life. When accident costs are based on willingness-to-pay concepts, program and project choices are more likely to represent the public's desires. (*3*, *4*)

Four basic methods have been used to estimate willingness to pay for life and safety: Asking people, deriving figures directly from economic theory, examining salary differences between dangerous and safe jobs, and examining the prices for products such as cars with varying levels of safety or tradeoffs people make between speed and safety. Most literature has focused on the value of life. In a review of the literature on these four methods to determine willingness to pay, it was concluded that the best studies using each method yielded generally consistent values of life between $1 million and $2 million. (*5*)

Approaches for Determining Accident Costs

Human capital approach

The human capital approach for determining accident costs includes direct costs and indirect social mechanism and human capital costs. Over the years, a major shift has occurred in the way human capital costs are determined. For a brief time during the 1960's, human capital minus consumption was an accepted method. This involved subtracting the amount that would be consumed in goods and services in an individual's remaining lifetime from the human capital the individual would supply. By the mid-1960's, there were criticisms of removing consumption. Today, most economists do not feel that the human-capital-minus-consumption method is appropriate to determine human capital costs. However, because the method was popular when the National Safety Council first generated its accident costs, the Council adopted the method. The method remains within the base numbers underlying the Council's annual updates of accident costs, which are used by many analysts in State highway agencies. (*6*)

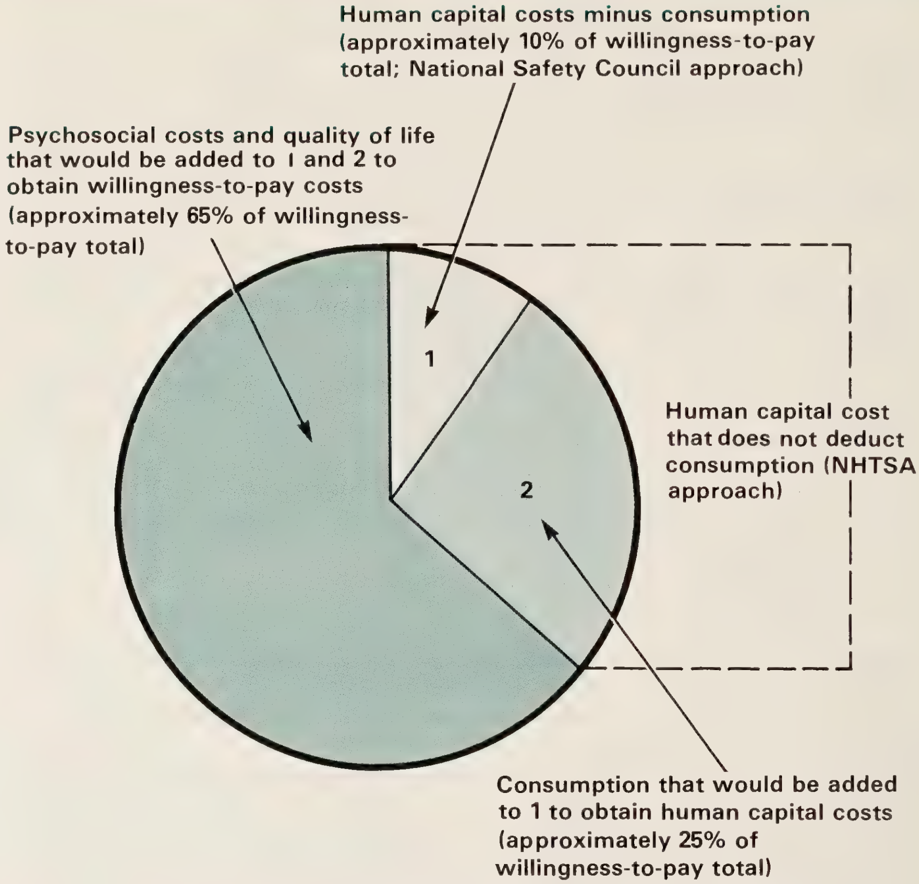

Figure 1.—Comparison of accident costs based on different approaches, where willingness to pay is the full circle.

As shown in figure 1, the human capital approach that does not deduct consumption (used by the National Highway Traffic Safety Administration [NHTSA]) generates cost figures approximately 2½ times larger than that of the National Safety Council. Such a magnitude of difference in a major component of accident costs greatly impacts total accident costs. The change in accident costs, in turn, would affect the determination of benefits in a benefit-cost analysis and could cause a countermeasure originally classified as not cost-beneficial to be classified as cost-beneficial.

The human capital approach puts a dollar value on death, and this dollar value only considers lost productivity. This approach does not consider the intangibles offered to society such as supportiveness, helpfulness, encouragement, and happiness, which also are part of a person's worth. Basing the approach on dollar values for lost productivity raises the issue of equal pay for equal work. Should women and minorities be valued less because often they earn less than men? Should the elderly have almost no value because of their limited productive years ahead? Are children, because they have nonproductive years before they join the workforce, valued less because their productive years must be averaged over their nonproductive years? Using the human capital approach implies that these groups, because of lower productivity values, have less value to society. The desireability of an accident cost approach that places low values on these groups is questionable. Furthermore, the human capital approach does not value any loss in quality of life (for example, mobility) or pain and suffering that are experienced both during recuperation from an accident and possibly later in life.

Willingness-to-pay approach

For comparison, table 3 shows accident costs computed using the human capital approach and the willingness-to-pay approach. The accident costs based on the human capital approach are derived from information from two documents representing the best sources in this area. (*7*, *8*) Unlike these sources, table 3 not only shows costs for each person or vehicle involved—that is, for each incident—but also costs per accident. The estimated costs per accident were based on data from NHTSA's National Accident Sampling System (NASS) on the number and severity of incidents per accident.

The willingness-to-pay accident and incident cost figures generated from the findings of the FHWA study and presented in table 3 include the same values for direct costs and the indirect social mechanism costs as in the human capital costs. They also include life values estimated using a methodology (*9*) that was extended to permit valuation of nonfatal injuries. (*5*)

The willingness-to-pay costs in table 3 are conservative. Economists at the Occupational Safety and Health Administration (OSHA) support using $3.5 million (in 1982 dollars) as the value of a life for regulatory justification. (*10*) The Office of Management and Budget (OMB) supports a $1 million value of life figure (*10*), which is very close to what this article suggests. Subsequently, OSHA and OMB compromised on a value of $2 million.

Table 3.—Cost per accident and per incident for a variety of accident severity kinds as derived by the willingness-to-pay approach and the human capital approach[1]

Severity by most severe injury	Willingness-to-pay approach: Cost per incident[3]	Willingness-to-pay approach: Cost per accident[3]	Human capital approach[2]: Cost per incident	Human capital approach[2]: Cost per accident
	Dollars	*Dollars*	*Dollars*	*Dollars*
Fatal	1,156,164	1,305,116	436,521	500,159
Injury	7,108	9,783	5,402	7,361
MAIS injury scale				
MAIS 5 injury	561,849	NC[4]	301,089	NC
MAIS 4 injury	115,254	NC	60,746	NC
MAIS 3 injury	16,592	NC	12,990	NC
MAIS 2 injury	6,705	NC	3,466	NC
MAIS 1 injury	3,015	4,388	2,888	4,203
A-B-C injury scale				
A injury	28,920	36,525	16,508	21,955
B injury	7,720	12,320	5,328	8,499
C injury	3,553	6,682	3,071	5,233
Property damage only	1,070	1,830	1,070	1,830
Average	3,457	3,924	2,538	2,821

[1] All calculations are based on a 5-percent discount rate and are expressed in 1984 dollars.
[2] Includes consumption.
[3] Includes income taxes lost to society and individual's willingness to pay to avoid death and injury.
[4] Not computable from available data.

The Choice of Accident Costs Makes a Difference

Even the conservative willingness-to-pay figures of table 3 are higher than those used by most highway analysts in benefit-cost analyses, suggesting that benefits are being undervalued and justifiable projects are being found unjustifiable because of the lower cost figures. Also, this means that the most cost-beneficial safety projects sometimes will not be the ones selected for implementation when budgets are limited.

This is easily illustrated. Consider, for example, a hazardous bridge end on a four-lane highway. A guardrail is proposed to reduce the hazard. Suppose installation and maintenance of the guardrail at this bridge end would cost approximately $5,500 (in 1984 dollars) and that the guardrail would reduce the expected number of injuries by one per year and increase the expected number of property-damage-only accidents by two per year. Using the human capital costs per accident in table 3, the benefit-cost ratio for the guardrail installation would be 0.6—that is, $7,361 – (2 × $1,830)/$5,500—and therefore would not be cost-effective (benefit-cost ratio ≥ 1.0 = cost-effective). Similarly, using the willingness-to-pay costs per accident in table 3, the benefit-cost ratio would be 1.11—that is, $9,783 – (2 × $1,830)/$5,500—and it would be cost-effective to install the guardrail. The different accident cost numbers changed what decision would be recommended.

Summary

How accident cost numbers are derived is important, and which accident cost numbers are used makes a difference in selecting accident countermeasures to implement. Some popular published numbers must not be blindly accepted. The willingness-to-pay numbers recommended in the study discussed in this article ($1.1 million for the value of a life and $1.3 million for the cost of a fatal accident—from table 3) resulted from careful examination of all sides of the major economic issues concerning accident cost derivation. They are conservative for current economic thought, yet they are considerably higher than figures currently used by some highway agencies and are more in line with the OMB/OSHA compromise of $2 million for the value of a life. The choice of numbers to use requires responsible decisionmaking to get the most for the money in terms of benefits for the public. Economically sound accident cost numbers are an essential tool for making responsible decisions.

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Kenneth A. Reinert is a research assistant at the Bureau of Business and Economic Research. He is a graduate student at the University of Maryland, Department of Economics, and provided key input for the FHWA study discussed in this article.

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[2]Reports with PB numbers may be purchased from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

State-of-the-Art Pile Load Test Program for the Third Lake Washington Bridge

by
Suneel N. Vanikar and LeRoy Wilson

Introduction

Washington State Department of Transportation (WSDOT) currently is reconstructing Interstate 90 in the Seattle area to increase traffic carrying capacity and eliminate existing traffic hazards. This reconstruction requires an 8,400-ft (2.6-km) long bridge to be built over Lake Washington at a cost of approximately $96 million. The main part of the bridge will be a floating structure that will cost approximately $64 million. Piers under the approaches to the floating bridge will be located in variable water depths up to 90 ft (27.4 m).

WSDOT geotechnical engineers initially recommended using either 48-in (1.2-m) diameter steel pipe piles or 54-in (1.4-m) diameter prestressed concrete cylinder piles, each with a design load of 300 tons (2.7 MN) (compression), for pier support of the approaches. However, it was felt that higher loads were possible provided they could be verified by load tests. The Federal Highway Administration (FHWA) concurred with WSDOT engineers and FHWA participated in a load test program by providing technical assistance, a mobile pile load test frame for static load testing, and dynamic pile testing equipment (pile analyzer) to monitor the piles during driving.

Reasons for the Load Test Program

The load test program was conducted for two major reasons—first, to determine if the allowable pile design load in compression could be increased, thereby saving considerable costs, and second, to evaluate pile driveability. Tension load tests were performed to verify the uplift capacity of piles. Because the subsurface soil profile at the bridge site consisted of a shallow deposit of loose silty sand and sandy silt underlain by very dense sandy gravel and fine-to-coarse sand deposit (glacial till), there was concern that the closed-ended piles might not penetrate deeply enough into the very dense till to provide sufficient uplift capacity. Also, pile driveability was of vital importance for the large-diameter closed-ended piles because they would be difficult to drive in the dense glacial till and might be susceptible to damage because of the large-size hammer required for driving.

Features of the Load Test Program

Two 48-in (1.2-m) diameter closed-ended pipe piles with specially designed tip extensions were load tested, one on each side of the lake, at locations where the lake was about 85 ft (25.9 m) deep (fig. 1). The piles were 160 ft (48.8 m) long and ¾ in (19 mm) thick. The pile wall thickness of ¾ in (19 mm) was determined necessary to keep the driving stresses within allowable limits based on wave equation analysis. Closed-ended load test piles were chosen to mobilize the tremendous end bearing capacity available in the very dense glacial till soils, allowing much shorter pile lengths than open-ended piles and thus reducing pile cost. One pile was fitted with a 10-ft (3-m) long fabricated H-shaped tip, and the other pile was fitted with a 10-ft (3-m) long open-ended pipe that was ¾ in (19 mm) thick and 48 in (1.2 m) in diameter. To evaluate the static pile load test, vibrating wire strain gauges and telltale extensometer rods were installed inside each test pile to provide vital data on the load transfer distribution between the pile and the soil. At each test site, four closed-ended piles 36 in (0.9 m) in diameter, ¾ in (19 mm) thick, and approximately 160 ft (48.8 m) long were used as reaction piles. All of the piles were fabricated in shop and barged full length to the project site.

Wave equation analysis indicated that the minimum hammer energy required to drive the piles would be 90,000 ft•lb (121.5 kJ). The load test piles were monitored during driving with the FHWA pile analyzer. The analyzer provided the static pile capacity, stresses in the pile during driving, and the hammer energy transferred to the pile under each blow.

The compression load test was conducted to a maximum load of 1,000 tons (8.9 MN) using the FHWA mobile pile load test frame, and the tension tests were performed until the pile uplift capacity was exceeded.

Results of the Load Test Program

The compression piles were driven, without damage, using a single-acting steam hammer with a maximum rated energy of 90,000 ft•lb (121.5 kJ). The pile with the H-shaped tip was driven 34 ft (10.3 m) into the lake bed, and the pile with the open-ended pipe tip was driven 16 ft (4.9 m) into the lake bed. The compression load tests for both test piles showed that the ultimate capacity was 1,000 tons (8.9 MN). Using a safety factor of 2, an allowable design load of 500 tons (4.4 MN) was recommended—significantly more than the initial design load recommendation of 300 tons (2.7 MN).

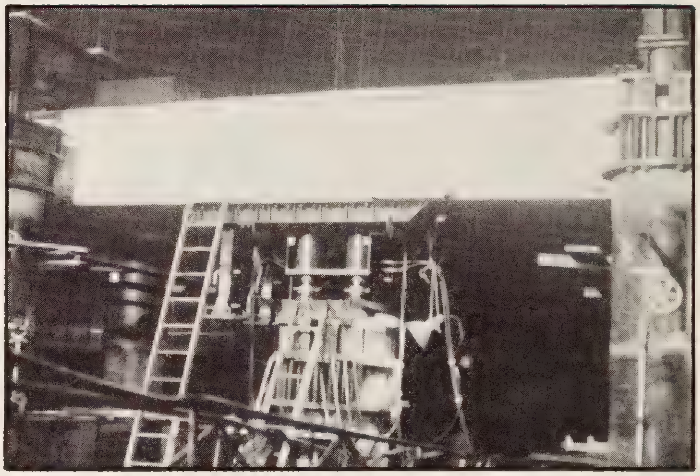


Figure 1.—Bridge pile load test setup.

The ultimate load capacity predicted by the pile analyzer during driving of the test piles was 780 tons (6.9 MN). Even though the analyzer tended to underestimate the load bearing capacity, it proved to be a valuable tool in monitoring the performance of the pile hammer and in monitoring the driving stresses in the pile.

The load transfer data obtained from the pile instrumentation indicated that the pile capacity was 90 percent in end bearing. This information was used in wave equation analysis for the production piles.

The uplift capacity of the pile with the H-shaped tip was exceeded at 250 tons (2.2 MN) of uplift load. The test pile with the open-ended pipe tip was damaged during driving where the pipe attached to the pile and failed under 50 tons (444 kN) of uplift load. Based on this information, WSDOT decided to use a larger H-shaped tip for production piles to provide the required uplift capacity.

The pile driveability of the ¾-in (19-mm) wall piles with an air/steam hammer with a maximum rated energy of 90,000 ft•lb (121.5 kJ) was confirmed. The maximum hammer energy transferred into the pile top, as measured with the pile analyzer, varied from 40,000 to 60,000 ft•lb (54 to 81 kJ). The pile wall thickness of ¾ in (19 mm) proved to be more than adequate. If the wave equation analysis had not been used before the load test to estimate driving stresses, a wall thickness of 1¼ in (32 mm) would have been specified.

Cost savings

The total cost of the load test program was $500,000.[1] Three quantifiable cost savings that resulted from the program are as follows:

- Fewer piles were used as a result of the load test verification of the 500-ton (4.4-MN) design capacity versus the 300-ton (2.7-MN) preliminary design estimate.
- Piles with ¾-in (19-mm) wall thicknesses were used versus piles with 1¼-in (32-mm) wall thicknesses as originally estimated.
- Smaller size pile caps will be required at each pier as a result of using fewer piles.

Another major cost savings that was realized, although not easily quantifiable, was the reduced pile driving prices that resulted from making all of the load test pile driveability information available to prospective construction bidders during the project advertisement. A net cost savings of approximately $5 million was realized on this project, providing a very favorable benefit-cost ratio of 10:1.[2]

Summary

This joint effort by FHWA and WSDOT demonstrates the value of using state-of-the-art structure foundation design and construction methods to provide more cost-effective pile foundations. On large-scale projects, the load test programs should be performed during the design stage rather than during the bridge construction stage because of a greater potential for cost savings. The detailed design of the load test program, good contract specifications, and excellent work by the contractor all contributed to the success of the pile load test program for the Third Lake Washington Bridge.

Suneel N. Vanikar is a geotechnical engineer in the Geotechnical and Materials Branch, Office of Highway Operations, FHWA. He is project manager for Demonstration Project No. 66 on pile foundations and is author of "FHWA Manual on Design and Construction of Driven Pile Foundations." His 21 years' experience includes bridge design and geotechnical engineering.

LeRoy Wilson is a foundation engineer in the Washington State Department of Transportation. He has worked in the Washington State government for 24 years and managed the bridge pile load test program discussed in this article.

[1] L. Wilson, "Pile Load Test at Lake Washington," internal document, Washington State Department of Transportation, Olympia, WA.

[2] Ibid.

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

Methods of Increasing Pedestrian Safety at Right-Turn-on-Red Intersections, Report No. FHWA/RD-85/047

by Safety Design Division

The study discussed in this report was conducted to determine current motorist compliance to right-turn-on-red (RTOR) regulations, develop and field test countermeasures for RTOR pedestrian accidents, and develop improved warrants and guidelines for RTOR. Based on data from several cities in the United States, only 3.7 percent of all right-turning drivers violate NO TURN ON RED (NTOR) signs. However, of drivers with an opportunity to turn right on red, 20 percent violated the sign. At RTOR locations, 56.9 percent of motorists do not come to a complete stop before turning right. In comparison, 68.2 percent of motorists do not come to a full stop at stop signs.

Based on conflict and violation data, 30 possible countermeasures were developed for RTOR pedestrian accidents. Six of these countermeasures were field tested, including an offset stop bar, a red ball (symbolic) NTOR sign, a larger 30- x 36-in (762-x 914-mm) NTOR sign, a LOOK FOR TURNING VEHICLES pavement marking, a NTOR WHEN PEDESTRIANS ARE PRESENT sign, and an electronic variable message (blankout) NTOR sign. Several promising applications for the countermeasures were recommended, and current MUTCD guidelines on RTOR prohibition were critiqued. Improved guidelines were recommended based on an analysis of conflicts at 199 intersection approaches.

The report may be purchased from NTIS (PB No. 86 100484).

Pedestrian Trip-Making Characteristics and Exposure Measures, Report No. FHWA/RD-85/074

by Safety Design Division

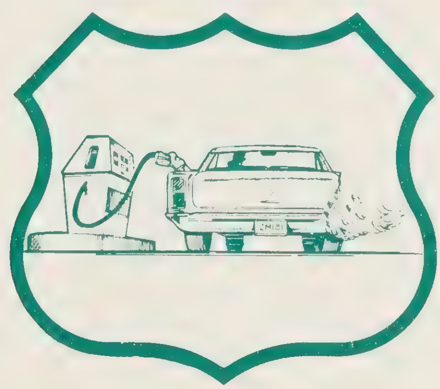
This report discusses a study that identified specific pedestrian trip-making characteristics, developed pedestrian exposure measures, and examined these trip-making characteristics and exposure measures relative to accident information to determine accident rates and the relative hazardousness of various pedestrian characteristics and behaviors.

A large-scale field study was conducted in five standard metropolitan statistical areas in the United States; 1,357 sites were measured, photographed, and described. Volume and activity data were recorded on 612,395 vehicles and 60,906 pedestrians. Also, 20,147 pedestrians were coded by demographic characteristics and behavior.

The report presents data on pedestrian trip-making characteristics and behavior—who walks, where they walk, how they walk (or run), and when they walk. Pedestrian exposure is described in terms of the number of pedestrian-vehicle (PxV) interactions. Exposure data are presented in terms of various pedestrian and site characteristics. Accident rates and relative hazardousness were determined by comparing the exposure data to pedestrian accident data. Accident rates and the relative hazard associated with various site characteristics, pedestrian and vehicle characteristics, and pedestrian and vehicle actions are presented.

The report may be purchased from NTIS (PB No. 86 100039).

Fuel Consumption and Emission Values for Traffic Models, Report No. FHWA/RD-85/053



by Traffic Systems Division

The study described in this report combined laboratory (dynamometer) testing with onroad testing to assess the energy and environmental characteristics of passenger vehicles as they operate in "real-world" conditions. The report documents the methodologies used in the development of fuel consumption and emission characteristics for 15 passenger vehicles representing 64 percent of the 1980-1992 population. Tables and graphs relating vehicular fuel consumption and emissions to speed and acceleration were developed.

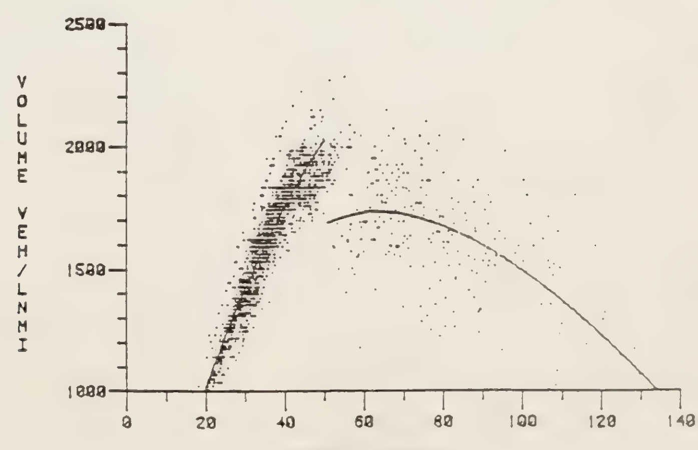
The report may be purchased from NTIS (PB No. 86 143963).

Demand-Responsive Strategies for Interconnected Freeway Ramp Control Systems, Vols. I-III, Report Nos. FHWA/RD-85/109-111

by Traffic Systems Division

These reports present the results of a study to develop a demand-responsive strategy for freeway ramp control. Specifically, surveillance data processing algorithms using the Kalman filter methodology and a ramp metering algorithm using a linear regulator from optimal control theory were developed.

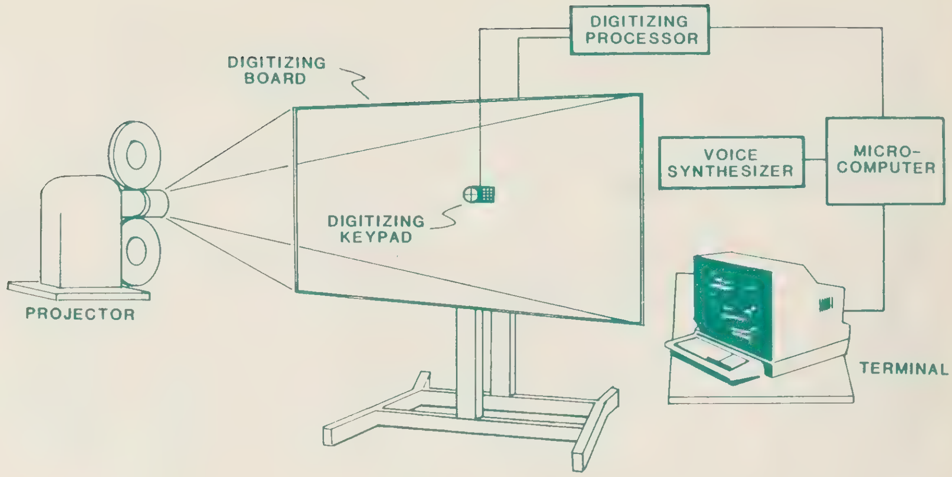
Volume I, **Metering Strategies**, discusses simulation testing of the demand-responsive control strategy developed using the macroscopic simulation program FREFLO. Results show that the regulator provides a demand-responsive control strategy capable of alleviating congestion at various levels of surveillance, effectively manages recurrent congestion by avoiding over-capacity densities, and provides an efficient mechanism for returning the freeway to an uncongested state after an incident.



Volume II, **Program Documentation,** presents the program documentation for the software written to support simulation testing using FREFLO. Software was developed to perform both the freeway surveillance and ramp metering functions necessary for demand-responsive control. The program documentation, in the form of code structure charts and source code listings, includes the software necessary to input the parameters, to perform the online computations, and to perform the offline computations required to operate FREFLO in a ramp metering mode.

Volume III, **Users Guide,** presents information for using the software for simulation testing with FREFLO. The users guide consists of data flow diagrams and sample inputs that should enable a user to run the software. Additionally, a discussion of the integration of the surveillance/control software system with existing hardware to control a real freeway system is included.

The reports may be purchased from NTIS (PB Nos. 86 122462, 86 122470, and 86 122488).



Freeway Data Collection for Studying Vehicle Interactions—Technical Report, Report No. FHWA/RD-85/108, and Appendixes H and I, Report No. FHWA/RD-86/023

by Traffic Systems Division

The study described in these reports was conducted to develop a series of data sets on microscopic vehicular traffic flow for selected kinds of freeway bottleneck sections. Six kinds of freeway geometry were of interest: Ramp merges, weaving sections, upgrade sections, reduced width sections, lane drops, and horizontal curves. The methodology used to develop these data sets involved digitizing vehicle positions from time-lapse aerial photography for a series of freeway sites under various geometric configurations. These data sets are expected to be useful for both empirical research on freeway traffic flow and for validating freeway simulation models.

Appendixes H and I describe the setup for the digitizing system and present the source code for the computer program.

The reports may be purchased from NTIS (PB Nos. 86 114667 and 86 114675).

Sign Luminance Requirements for Various Background Complexities, Report No. FHWA/RD-85/056

by Traffic Safety Research Division

The Federal standards for luminance of retroreflective materials for traffic signs are acceptance standards; they provide no differentiation in luminance based on driver need. Sign luminance affects sign comprehension, legibility, and conspicuity. This report describes research to establish, for different levels of scene complexity, luminance levels for conspicuity of yellow diamond warning signs at night. A procedure based on rating sign locations on four subjective scales was found useful for identifying complexity scenes that required signs with different sign luminance levels.

The results clearly support earlier research in demonstrating that the visual complexity of a scene is important in determining nighttime sign luminance requirements.

The report may be purchased from NTIS (PB No. 86 127545).

Screening of Structural Adhesives for Application to Steel Bridges, Report No. FHWA/RD-86/037

by Structures Division

This interim report presents the preliminary findings of a study to determine whether adhesives are durable enough to replace welded connections in highway bridge members in typical bridge environments. The focus of most previous research has been limited to studying the effects of temperature changes on the mechanical properties of bulk specimens and bonded specimens. Although the detrimental effects of water were recognized, few studies attempted to quantify its effect, and no study let the water content in the bulk adhesive equilibrate with the relative humidity of the ambient environment. These environmental effects are addressed in this report.

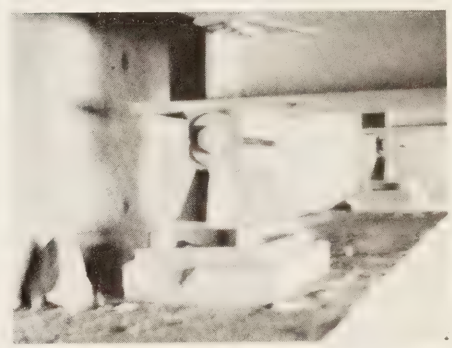
The results of pilot tests of polymetric materials and screening tests of adhesives are presented. The report also explores the equations needed to analyze the behavior of adhesives using concepts of thermodynamics of elasticity.

The report may be purchased from NTIS (PB No. 86 142601).

Tolerable Movement Criteria for Highway Bridges, Report No. FHWA/RD-85/107

by Materials Division

This report describes a new method that uses a rational set of tolerable movement criteria for designing bridges and their foundations. This new design method emphasizes the optimization of the design of the superstructure and its supporting substructure as a single integrated system offering the best combination of long-term performance and economy. Tolerable movement criteria based on strength and serviceability are presented, in terms of limiting longitudinal angular distortion, horizontal movements of abutments, deck cracking, and bridge vibrations. The supporting data from analytical and field performance studies also are described for steel and concrete bridges.



Limited copies of the report 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

Guidelines for the Administration of Highway Construction Claims, Report Nos. FHWA-TS-85-215/218

by Office of Implementation

Four final reports resulted from a study conducted to alleviate the confusion caused by current methods for settling contractor claims against State highway agencies and the Federal Highway Administration (FHWA) and to recommend new guidelines to reduce the number of claims filed.

The first report, **Highway Construction Contract Claims: Causes and Resolution Practices,** Report No. FHWA-TS-85-215, is a comprehensive investigation of the origin of claims, practices, and procedures in eight selected States.

The second report, **Analysis of FHWA Participation in Highway Construction Claims,** Report No. FHWA-TS-85-216, describes the role of FHWA in the settlement process and presents recommendations for improvement.

The third report, **Comparative Analysis of Time and Schedule Performance on Highway Construction Projects Involving Contract Claims,** Report No. FHWA-TS-85-217, discusses specific aspects of contract administration and claims, especially scheduling and time problems.

The fourth report, **A Synthesis of the Prequalification Procedures of Six State Departments of Transportation,** Report No. FHWA-TS-85-218, examines contractor prequalification practices.

The reports may be purchased from NTIS (PB Nos. 86 122520, 86 122678, 86 122538, and 86 122686).

Portland Cement Concrete Pavement Pulverizing Equipment, Report No. FHWA-TS-85-224

by Office of Implementation

Portland cement concrete (PCC) commonly is broken up using gravity drop hammers, trailer-mounted diesel hammers, spring arm hammers, and vibrating beam breakers. Removal of steel in PCC is a labor-intensive, low-production operation. Breaking and crushing operations need to be improved so that large quantities of coarse aggregate can be produced from PCC. Field operations need to be improved to prevent or reduce the amount of base course contamination.

Considering the condition of pavements in the United States, the current recycling quantities, and the expected growth of recycling, 50 to 100 equipment units will be required in 20 years to break or pulverize PCC pavements. Because funding for new equipment has been slow to develop, Federal and State governments may have to include several large projects in a single contract to provide the volume of work necessary to pay the "front-end" costs for innovative equipment development.

The report may be purchased from NTIS (PB No. 86 123544).

Proceedings, Workshop in Pavement Rehabilitation, Report No. FHWA-TS-84-224

by Office of Implementation

The Workshop in Pavement Rehabilitation, held in Salt Lake City, Utah, September 17-20, 1984, was attended by more than 135 people from the Federal, State, and local governments, as well as industry and academia. This report includes 47 of the 49 papers presented at the workshop.

These proceedings cover most aspects of asphalt concrete pavement and portland cement concrete pavement rehabilitation including recycling, overlay design, relief joints, load transfer, and drainage. Life cycle costs, traffic loading, traffic control, and maintenance were addressed. In addition, national rehabilitation policies, perspectives of industry, and ongoing research are discussed.

The report may be purchased from NTIS (PB No. 85 214260).

Roadway Evaluation Equipment Workshop, Report No. FHWA-TS-85-210

by Office of Implementation

The Roadway Evaluation Equipment Workshop was held September 24-26, 1984, in University Park, Pennsylvania. Recently developed equipment for measuring and evaluating pavement condition was discussed in formal presentations to State transportation personnel and was demonstrated at the Pennsylvania Transportation Institute's research facilities. Testing and calibration methods essential for roadway management systems also were presented, and 24 presentations are included in this report. Among the devices discussed are the Mays ride meter, roughness surveyor, Swedish laser road surface tester, and the falling weight deflectometer.

The report may be purchased from NTIS (PB No. 85 220226).

Proceedings, Tri-Regional Pavement Rehabilitation Conference, Report No. FHWA-TS-84-223

by Office of Implementation

This conference, held May 14-17, 1984, in Oklahoma City, Oklahoma, provided a forum for practicing engineers, administrators, and industry representatives to discuss and demonstrate both proven and the most promising technology available for the evaluation and rehabilitation of pavement systems in the United States.

The agenda included speakers and other participants from 17 States, 3 leading universities, the construction industry, and representatives of companies that manufacture state-of-the-art automated pavement data collection systems, including the latest equipment from other countries. The latest concrete pavement rehabilitation techniques were demonstrated onsite, and several of the latest automated data collection systems were demonstrated and displayed. The papers presented in this report are reprinted from the authors' original papers.

The report may be purchased from NTIS (PB No. 85 183812).

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: Fundamental Studies on Speed Zoning and Control. (FCP No. 31A4054)
Objective: Define realistic speed zoning and develop the traffic engineering tools to derive it by understanding why motorists break speed laws and how they perceive existing speed limits. Conduct controlled speed limit trials to determine the basic relation between changes in speed limits and changes in accident risk. Emphasize developing speed zoning and controls that promote voluntary compliance and provide the best traffic service for a given set of conditions. Examine absolute and prima facia speed limits, legal issues, public acceptance, and cost/performance tradeoffs.
Performing Organization: Martin Parker and Associates, Canton, MI 48187
Expected Completion Date: April 1989
Estimated Cost: $50,000 (FHWA Administrative Contract)

FCP Project 1P: Night Visibility

Title: Tradeoff Between Delineation and Lighting on Freeways. (FCP No. 31P2024)
Objective: Determine freeway interchanges that require lighting and those that can be treated effectively with improved delineation techniques such as raised pavement markers. Conduct driver performance studies to develop cost-effectiveness information for both clear and wet weather.
Performing Organization: IFR Applications, State College, PA 16801
Expected Completion Date: January 1988
Estimated Cost: $233,510 (FHWA Administrative Contract)

FCP Project 1Z: Implementation of Safety R&D

Title: Speed Control Through Work Zones—Technique Evaluation. (FCP No. 31ZA318)
Objective: Determine the long-term speed effects of innovative flagging, law enforcement, variable message signing, and roadway narrowing when used to control traffic in highway work zones. Develop a brief guideline on work zone speed control for incorporation in the "Traffic Control Devices Handbook."
Performing Organization: Daniel Consultants, Inc., Columbia, MD 21405
Expected Completion Date: December 1986
Estimated Cost: $121,400 (FHWA Administrative Contract)

FCP Category 2—Traffic Control and Management

FCP Project 2Q: Urban Network Control

Title: Enhancements to Passer II-84. (FCP No. 42Q1425)
Objective: Improve the treatment of permissive left turns by modifying the current delay model in Passer II-84.
Performing Organization: Texas Transportation Institute, College Station, TX 77840
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1987
Estimated Cost: $80,000 (HP&R)

FCP Category 4—Pavement Design, Construction, and Management

FCP Project 4A: Pavement Management Strategies

Title: Pavement Design Using Rapid Methods of Collecting and Analyzing Deflection Data—Design Procedure Development. (FCP No. 44A3102)
Objective: Develop a rational pavement design procedure for highways and general aviation airfields. Use the procedure in the design of new pavement sections where material properties can, to some extent, be controlled and in the design of overlays for existing pavements.
Performing Organization: Tennessee Department of Transportation, Nashville, TN 37219
Expected Completion Date: March 1987
Estimated Cost: $113,660 (HP&R)

FCP Project 4B: Design and Rehabilitation of Rigid Pavements

Title: Assessment of Load Transfer Across Joints and Cracks in Rigid Pavements Using the Falling Weight Deflectometer (FWD). (FCP No. 44B2324)
Objective: Field test procedures previously developed for evaluating transverse joint efficiency using an FWD and modify, if necessary, to evaluate transverse cracks. Develop a method for using the FWD to evaluate cracks in rigid pavements for load, shear, and moment transfer and to evaluate longitudinal joints, particularly between the mainline and a tied concrete shoulder.
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: $280,500 (HP&R)

FCP Project 4C: Design and Rehabilitation of Flexible Pavements

Title: Potential Benefits of Geosynthetics in Flexible Pavement Systems. (FCP No. 54C1213)
Objective: Evaluate the potential structural and economic advantages of geosynthetic reinforcement within a granular base and develop practical design guidelines.
Performing Organization: Georgia Institute of Technology, Atlanta, GA 30332
Expected Completion Date: December 1987
Estimated Cost: $50,000 (NCHRP)

Title: Increase of Recycled Asphalt Production Through Use of Styrene-Butadiene Rubber (SBR) Latex. (FCP No. 44C3174)
Objective: Determine whether the use of SBR latex in combination with virgin asphalt and aggregate can be added to recycled materials to improve pavement performance.
Performing Organization: University of Akron, Akron, OH 44325
Funding Agency: Ohio Department of Transportation
Expected Completion Date: March 1987
Estimated Cost: $43,000 (HP&R)

Title: Correction of Wheelpath Rutting. (FCP No. 44C6314)
Objective: Evaluate a proprietary slurry seal type material called "Ralumac" (a blend of latex-modified emulsion, aggregate, type 1 portland cement, water, and additive) used to correct wheelpath rutting in asphalt pavements.
Performing Organization: New Jersey Department of Transportation, Trenton, NJ 08625
Expected Completion Date: July 1989
Estimated Cost: $56,710 (HP&R)

FCP Project 4E: Construction Control and Management

Title: Integration of New Portland Cement Concrete (PCC) Smoothness Monitoring Equipment Into Current Procedures and Specifications. (FCP No. 34E1183)
Objective: Develop data and correlations between outputs from a new device that automatically measures, displays, and records the smoothness of newly placed pavement and those from the current devices. Develop standard procedures and other supporting information that will make the new device easy to use and readily accepted by both contractors and State highway agencies.
Performing Organization: Analysis Group, Inc., Washington, DC 20003
Expected Completion Date: March 1987
Estimated Cost: $74,740 (FHWA Administrative Contract)

FCP Category 5—Structural Design and Hydraulics

FCP Project 5A: Bridge Loading and Design Criteria

Title: Fatigue of Cables in Cable-Stayed Bridges. (FCP No. 55A2012)
Objective: Develop criteria and guidelines for fatigue design of cable stays, and develop practical guidelines for material requirements and for testing wires, strands, and cable stays.
Performing Organization: Freeman Fox Ltd., London, UK
Expected Completion Date: June 1987
Estimated Cost: $125,000 (NCHRP)

Title: Fatigue Strength of Post-tensioned Concrete. (FCP No. 45A2202)
Objective: Examine the fatigue resistance of typical posttensioned concrete girders to determine the effective level of tension stress in the precompressed tensile zone on the capability of posttension girders to withstand traffic loading without fatigue during their design service life. Consider kind of duct, effect of tendon coating, and effect of grouting materials on the fatigue strength of both tendon assemblies and girder.
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: $100,000 (HP&R)

Title: Guidelines for Multiple-Span Highway Bridges Without Joints. (FCP No. 35A3182)
Objective: Review current design and construction practices and field problems that have developed in long, multiple-span bridges without expansion joints. Compile a state-of-the-art report on this subject and develop comprehensive guidelines for designing such bridges. Address such topics as length and number of spans, kinds and flexibility of piers, kinds of foundations and bearings, and other appropriate design features.
Performing Organization: University of Maryland, College Park, MD 20742
Expected Completion Date: March 1987
Estimated Cost: $94,890 (FHWA Administrative Contract)

Title: Augmentation of Shortcut Design Techniques for Concrete Box Girders. (FCP No. 45A4082)
Objective: Provide a complete software package for use in the design of concrete box girder bridges with monolithic slabs.
Perfoming Organization: California Department of Transportation, Sacramento, CA 95807
Expected Completion Date: September 1987
Estimated Cost: $40,000 (HP&R)

☆ U.S. Government Printing Office: 1986—491-825/40003

FCP Project 5H: Highway Drainage and Flood Protection

Title: Microcomputer Software for Storm Drain Hydraulic Grade Line Computations. (FCP No. 45H3722)

Objective: Develop and code hydraulic grade line procedures for the storm drain program that wil! be incorporated into the integrated drainage design computer system.
Performing Organization: University of Virginia, Charlottesville, VA 22903
Funding Agency: Virginia Department of Highways and Transportation
Expected Completion Date: June 1987
Estimated Cost: $33,500 (HP&R)

Title: Overtopping Damage Minimization. (FCP No. 35H4062)

Objective: Evaluate the performance of various roadway surface and embankment treatments, and conduct scale model tests of a select group of the most promising treatments to determine the most effective, esthetic, maintenance-free, and inexpensive systems for stabilizing embankments during overtopping.
Performing Organization: Simons, Li, and Associates, Inc., Fort Collins, CO 80522
Expected Completion Date: May 1988
Estimated Cost: $90,000 (FHWA Administrative Contract)

FCP Project 5K: Bridge Rehabilitation Technology

Title: Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges. (FCP No. 55K2122)

Objective: Develop practical guidelines to assess the effects of corrosion on structural details in steel highway bridges. Ensure that the guidelines apply to all of the steps involved in evaluating the effects of corrosion on the performance of existing bridges and that they are suitable for incorporation into AASHTO's "Manual for Maintenance Inspection of Bridges."
Performing Organization: Modjeski and Masters, Inc., Harrisburg, PA 17105
Expected Completion Date: September 1988
Estimated Cost: $300,000 (NCHRP)

Title: Strategies for Bridge Replacement. (FCP No. 45K4062)

Objective: Develop a practical methodology for prioritizing bridge structure rehabilitation and replacement for both onsystem and off-system bridges in Texas.
Performing Organization: Center for Transport Research, Austin, TX 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1988
Estimated Cost: $80,000 (HP&R)

FCP Project 5Z: Implementation of Structural and Hydraulics R&D

Title: Microcomputer Programs for Hydraulic Design of Drainage Structures. (FCP No. 35ZH088)

Objective: Develop microcomputer programs for various hydraulic design procedures, and write a users manual detailing the program and its proper use. Develop programs for the following design areas: Bridge waterways, culvert outlet protection, open channels, pumping stations, local scour, storm drainage systems, reservoir routing, and structural culvert design.
Performing Organization: University of Colorado at Denver, Denver, CO 82020
Expected Completion Date: December 1986
Estimated Cost: $49,945 (FHWA Administrative Contract)

FCP Category 0—Other New Studies

Title: Concrete Coating Problems. (FCP No. 40M3972)

Objective: Evaluate the problems with concrete coatings, including reported cases of flaking, peeling, and darkening. Conduct a laboratory and field exposure program to investigate conformance of materials to Texas' specifications and performance of various coatings and surface preparation variables.
Performing Organization: University of Texas at Austin, Austin, TX 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1986
Estimated Cost: $50,000 (HP&R)

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