HIGHWAY RESEARCH RECORD

Number 170

Traffic Control Devices

5 Reports

Subject Area

22	Highway Design
52	Road User Characteristics
53	Traffic Control and Operations

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

Washington, D.C., 1967
Publication 1500

Department of Traffic and Operations

Harold L. Michael, Chairman
Associate Director, Joint Highway Research Project
Purdue University, Lafayette, Indiana

HIGHWAY RESEARCH BOARD STAFF

E. A. Mueller, Engineer of Traffic and Operations

COMMITTEE ON OPERATIONAL EFFECTS OF GEOMETRICS

(As of December 31, 1966)

Asriel Taragin, Chairman
Assistant Deputy Director, Office of Research and Development
U.S. Bureau of Public Roads, Washington, D.C.

Stanley R. Byington, Secretary
Traffic Systems Division, Office of Research & Development
U.S. Bureau of Public Roads, Washington, D.C.

Patrick J. Athol, Project Supervisor, Illinois Expressway Surveillance Project, Oak Park
W. R. Bellis, Director of Research and Evaluation, New Jersey State Highway Department, Trenton
Louis E. Bender, Chief, Traffic Engineering Division, The Port of New York Authority, New York, N.Y.
Ralph D. Brown, Jr., Engineer of Location and Roadway Planning, Illinois Division of Highways, Springfield
Robert R. Coleman, Assistant Director, Bureau of Traffic Engineering, Pennsylvania Department of Highways, Harrisburg
James J. Crowley, Assistant Regional Engineer, U.S. Bureau of Public Roads, Fort Worth, Texas
Harley T. Davidson, Engineer of Design Development, Connecticut State Highway Department, Wethersfield
William G. Galloway, Director, Division of Traffic, Kentucky Department of Highways, Frankfort
George F. Hagenauer, DeLeuw, Cather & Company, Chicago, Illinois
John W. Hutchinson, Department of Civil Engineering, University of Kentucky, Lexington
Harry H. Iurka, Senior Landscape Architect, New York State Department of Public Works, Babylon, Long Island
Thomas W. Kennedy, Center for Highway Research, The University of Texas, Austin
Richard A. Luettich, Planning and Traffic Engineer, Maine State Highway Commission, Augusta
Karl Moskowitz, Assistant Traffic Engineer, California Division of Highways, Sacramento
R. C. O'Connell, Highway Safety Engineer, Planning and Standards Division, Office of Highway Safety, U.S. Bureau of Public Roads, Washington, D.C.
Neilon J. Rowan, Assistant Research Engineer, Texas Transportation Institute, Texas A & M University, College Station
W. T. Spencer, Assistant Chief, Division of Materials and Tests, Indiana State Highway Commission, Indianapolis
John H. Swanberg, Chief Engineer, Minnesota Department of Highways, St. Paul

COMMITTEE ON TRAFFIC CONTROL DEVICES

(As of December 31, 1966)

Robert E. Conner, Chairman
Chief, Traffic Engineering Branch, Office of Highway Safety
U.S. Bureau of Public Roads, Washington, D.C.

W. C. Anderson, Chief Research and Development Engineer, Union Metal Manufacturing Company, Canton, Ohio
Donald S. Berry, Chairman, Department of Civil Engineering, The Technological Institute, Northwestern University, Evanston, Illinois
C. E. Billion, San Diego, California
James W. Booth, Chief Traffic Engineer, Utah State Road Commission, Salt Lake City
Abner W. Coleman, Traffic Engineer, Vermont Department of Highways, Montpelier
F. B. Crandall, Traffic Engineer, Oregon State Highway Department, Salem
J. E. P. Darrell, Minnesota State Automobile Association, Minneapolis
Robert D. Dier, Traffic Engineer, Long Beach, California
William H. Dorman, Lighting Product Development Laboratory, Corning Glass Works, Corning, N.Y.
Anthony J. Galioto, Engineer of Traffic Control, The Port of New York Authority, New York, N.Y.
Daniel L. Gerlough, Head, Traffic Systems Section, Planning Research Corporation, Los Angeles, California
Alan T. Gonseth, Senior Research Analyst, The Port of New York Authority, New York, N.Y.
J. T. Hewton, Operations Engineer, Traffic Engineering Department, Municipality of Metropolitan Toronto, Toronto, Canada
George W. Howie, Eastern Regional Transportation Engineer, DeLeuw, Cather & Associates, New York, N.Y.
Matthew J. Huber, Bureau of Highway Traffic, Yale University, New Haven, Connecticut
Rudolph J. Israel, Assistant Traffic Engineer, Traffic Department, California Division of Highways, Sacramento
James H. Kell, Principal Traffic Engineer, Traffic Research Corporation, San Francisco, California
Frank S. Kovach, Assistant Superintendent of Signal Systems, Akron, Ohio
Joseph E. Lema, Highway Safety Specialist, Planning and Standards Division, Office of Highway Safety, U.S. Bureau of Public Roads, Washington, D.C.
Holden M. LeRoy, Traffic Control Engineer, Department of Streets and Traffic, Detroit, Michigan
Phillip S. Mancini, Chief, Division of Traffic Engineering and Highway Planning, Rhode Island Department of Public Works, Providence
J. Carl McMonagle, Institute for Community Development, Michigan State University, East Lansing
Fred J. Meno, II, Electrical Engineer, Public Lighting Commission, City of Detroit, Detroit, Michigan
William J. Miller, Jr., Director, Delaware River and Bay Authority, New Castle
J. P. Mills, Jr., Traffic and Planning Engineer, Virginia Department of Highways, Richmond
James V. Musick, Chief Traffic Engineer, Division of Traffic Engineering and Parking, Columbus, Ohio
A. R. Pepper, Traffic Engineer, Colorado Department of Highways, Denver
Marshall M. Rich, Wilbur Smith and Associates, Melbourne, Victoria, Australia
Frank G. Schlosser, Chief Engineer, Pfaff and Kendall, Newark, New Jersey
J. R. Stemler, Development Engineer, Aluminum Company of America, New Kensington, Pennsylvania
Rex G. Still, Traffic Engineer, Washington State Highway Commission, Olympia
Asriel Taragin, Assistant Deputy Director, Office of Research and Development, U.S. Bureau of Public Roads, Washington, D.C.

James A. Thompson, Chief, Lighting and Traffic Control Branch, U.S. Bureau of Public Roads, Washington, D.C.
Robert E. Titus, Director, Traffic Engineering Division, West Virginia State Road Commission, Charleston
Arthur M. White, Traffic Control and Safety Engineer, Mississippi State Highway Department, Jackson
Earl C. Williams, Jr., State Traffic Engineer, Tennessee Department of Highways, Nashville
Robert M. Williston, Chief of Traffic, Connecticut State Highway Department, Wethersfield
David K. Witheford, Transportation Planning Consultant, West Haven, Connecticut

Foreword

The increased attention being concentrated on aspects of traffic engineering as evidenced by Federal programs such as TOPICS is also manifested in the papers in this RECORD which portray recent research efforts in the field of traffic control devices. All types of devices were studied, from markings to median barriers, from freeway signing to traffic signals, and the sum of these efforts serves to extend the frontiers yet a little further onward. Traffic engineers, designers and operations personnel will find these papers to be of assistance in pointing out new aspects not previously known and considered.

Two Washington, D. C., authors have extensively studied the signing problems inherent in suburban Interstate loop highways and have set forth at least three fundamental signing concepts that might help in providing better information to the motorist. Extensive data were analyzed by the researchers in arriving at their findings, application of which should provide more adequate directional guidance for the motorist. The paper also has three written discussions and an authors' closure which enhances its value.

A Minnesota researcher has studied the effect of "rumble strips" at rural stop-signed intersections and found that these strips significantly reduce speed of approaching traffic and numbers of stop sign violations. While statistically significant accident analyses could not be made, a decreasing trend in the number of accidents was found at two of the installations.

Evaluation and improvement of traffic signal settings were studied by two Massachusetts researchers using traffic simulation techniques. The half-dozen significant conclusions indicated that while better traffic performance might be achieved, the number of variables and interdependent traffic characteristics made such suggested signal settings highly dependent on traffic flow characteristics.

A Pennsylvanian has studied the effectiveness of a median barrier guardrail using traffic volume, accident occurrence, and photography in a unique application of the three. Results indicated more accidents occurred after the median installation, with interchange areas and curves recording the most impacts. In a 12-month period it was found that about 300 vehicles suffered initial or additional damages due to the installation but also that some 330 vehicles would have encroached on the median if the rail barrier has not been installed.

The problems associated with the ability of signs to compel motorists' attention during daytime driving conditions were extensively studied by two Minnesota researchers. Basic information on the nature and frequency of sign backgrounds was provided and the need was established for improved sign positioning relative to the driver's visual axis. From the information presented, the achievement of better sign design should be possible.

Contents

Motorists' Reactions to Signing on a Beltway

STEPHEN G. PETERSEN and DAVID W. SCHOPPERT, Alan M. Voorhees and Associates

Limited-access highways in the form of closed loops (beltways) around urban areas are a relatively new addition to highway geometry and the standards for signing linear routes are not completely applicable to a beltway. Therefore, the principal objective of this study was to obtain and evaluate information from motorists on the kinds of sign messages they need and desire to drive a beltway safely and efficiently.

The Capital Beltway (I-495) around Washington, D.C., was chosen as a laboratory and the motorists who use it as test subjects. Questionnaires were circulated to various groups of motorists to collect comments on the existing signing. The comments were combined with information obtained in a meeting of highway engineers and from work done previously in California to develop three signing concepts.

•THE building of the Interstate system of highways is bringing into reality a highway form which has been the dream of road builders and motorists since the time of the first central city traffic jam. The through motorist or the man who lives on one side of the central city but works on the other has always believed there should be a bypass or loop around the congested area so that he could avoid it. Many states built bypass routes but, because they were not limited access, they soon became as congested as the primary route through the central city.

The passage of the 1956 Highway Act with its provisions for a system of Interstate and Defense Highways provided an opportunity to build bypass routes which could be protected from the debilitating effects of roadside development. Thus, the dream of high-speed, free-flowing bypass highways is rapidly becoming a reality in city after city. In some cases, the bypasses form a closed loop and have a distinctive route number. In other cases, separate bypass routes are connected by short sections of highway to form a continuous highway loop or beltway. In either case, the benefits are manyfold but there are also problems. The purpose of this paper is to explore one set of problems which the closed highway loop, hereafter referred to as the beltway, creates; namely, those related to signing.

The historical experience of the highway engineer has been with linear routes between major points or routes radiating from a central city. Rules and guidelines have grown from this experience and have been formulated into signing manuals such as the "Interstate Sign Manual" (7) and the "Uniform Manual" (10). Thus, when it came time to sign the first beltways, the same freeway signing practices used on linear routes were applied to the beltway. As the signing engineer soon learned, the combination of close interchange spacing, a multiplicity of communities around the urban center and a route with neither beginning, end, nor direction makes a beltway and its intersecting routes particularly difficult to sign using practices developed for linear routes.

The principal objective of this study was to obtain and evaluate information from motorists on the kinds of sign messages they need and desire to drive a beltway safely and efficiently. The Capital Beltway, I-495, around Washington, D.C., was selected

---

Paper sponsored by Committee on Traffic Control Devices and presented at the 46th Annual Meeting.

as the laboratory and the motorist using it as test subjects. All signing on and leading to the Beltway was inventoried along with that on selected radial routes. This provided the study with a set of present conditions which are described in the section dealing with the laboratory.

The next step was to establish contact with Beltway users. After reviewing and discarding a number of methods, it was decided to use two variations of a basic questionnaire. One of these was directed at motorists who had used Citizen Band radios to call for help in finding their way. The other was to circulate a questionnaire to a typical cross section of area residents as found in a centrally located government office building. These two studies were then compared with a survey of Beltway users conducted by the D.C. Division of the American Automobile Association through its monthly magazine.

These three surveys combined produced over 900 written responses for compilation and review. Each study is described, and detailed results are presented, in a following section. Another phase of the study, in which field observations were made of driver behavior at selected interchanges, is also included.

A unique phase of the study was a meeting of six highway engineers who have responsibilities for, or close association with, freeway signing. This group provided a professional viewpoint with which user comments could be compared.

An effort was made to obtain accident information, but inquiries of state officials involved indicated that a correlation between signing and accidents had not been established from available accident reports. Specific reports examined by the researchers provided no clues directly relating signing with accidents. The inability to ascertain any valid connection through report interpretation caused abandonment of this approach.

The conclusions drawn from the collected data are set forth in the final section and summarized briefly below.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

If a single word could summarize the findings of this study, the one chosen would be "orientation." The comments from motorists, the statements of the experts and the observations of the study staff all lead to the same conclusion.

A motorist on a freeway is isolated from the world around him. He is rarely able to slow down safely to really deliberate about the decisions which face him and must, therefore, be led along in such a way that he is confident of where he is at all times. His landmarks are guide signs and on these he must rely for complete, accurate and understandable information. The challenge of freeway signing then is to keep the driver continuously informed of his general location with respect to destination and optimum routing. The principles of effective freeway signing are embodied in the following three concepts:

Concept 1: Provide orientation through the consistent application of a series of sign elements which will provide sequential and confirmatory information for the motorist. From all that could be learned as the investigation progressed, it appears that the interchange sequence sign is an effective means of achieving this required continuity. The interchange sequence sign should be made a standard element of freeway signing when the freeway is a beltway. It also has application on other freeway routes.

Concept 2: Establish route numbers and route names as the primary elements of interchange guide signs and reserve the use of place names for selected locations where they give the motorist directional orientation which could not otherwise be provided. Although the investigation revealed a pattern similar to previous studies in regard to the items of directional information used, a willingness was detected to operate increasingly with the names and numbers of principal routes, particularly the Interstate system. This leads logically to an emphasis on route names and numbers as primary signing elements and a phasing out of place names on freeway signing, except under conditions where important place names can provide optimum directional orientation for the motorist.

Concept 3: At the interchange of a radial route with a beltway, limit signing destinations to route intersections, regional areas and identifiable physical features on the beltway route, and exclude destination names except as a supplemental guide not normally repeated in the interchange signing sequence. This third concept developed from the second and deals primarily with the problem of providing directional orientation to the driver on a linear route intersecting a beltway. Closed loop facilities do not have readily definable directional characteristics and thus cannot be signed effectively with cardinal directions. Place names are not an effective alternate because the satellite communities along the beltway are often little more than bedroom towns for a large central city. However, the finding that motorists do recognize the Interstate system route numbers reinforces this third concept which suggests the use of major route interchanges around a beltway as destination points which the local stranger will recognize and which the out-of-the-area driver can easily identify on a map. Rest areas on major radials which are equipped with a large scale map, plus smaller printed ones for motorist use, would be major aids in supporting a change to a route number destination system.

From these concepts, specific criteria can be drawn for each of the eleven elements in freeway signing. The project revealed three areas where additional studies would provide insight into motorists' needs in freeway signing. One deals with a means of measuring motorist reaction to signing through field observations. The initial work undertaken here indicates that relatively short periods of observation can reveal problem locations. The second study suggested by this research is an in-depth analysis of driver behavior as affected by signing, under conditions of familiar surroundings compared with unfamiliar surroundings. Such a study under controlled conditions would help to verify the concepts developed in this paper. A third study which would help to resolve many existing problems would be expanded research on the use of symbols on freeway guide signs, particularly in conjunction with a beltway.

THE LABORATORY

One of the first interstate "beltways" to be completed was around Washington, D. C. Designated the Capital Beltway (I-495), it forms a continuous 66-mile loop passing through Maryland and Virginia and twice crosses the Potomac River, which separates the two states. The loop is on a radius of 7 to 11 miles from mile zero on the south lawn of the White House. Figure 1 shows Washington and the Beltway in relation to the regional highway network. Figure 2 shows the route in relation to the central city. Portions of this route were opened as early as 1962 but the final link was not opened until November 1964. Specifically regarding signing, the Maryland sections were opened with temporary signs which were replaced in a series of sign contracts ending in mid-1965. Virginia, on the other hand, installed permanent signs with each roadway contract but has been changing and installing additional signs throughout 1965 and early 1966.

Figure 2 shows that the loop is intersected by Interstate Routes 95, 66, 270, 70-S and 295. Except for I-270, each of these will penetrate to the central city but as yet none has been built and only I-95 on the south side of the city has been signed as an I-route. US Routes 1, 50 and 29 pass through the central city and, except for US 29, intersect the Beltway on each side of the loop. US 29 has an interchange on the north (Maryland) side of the loop but not on the west (Virginia) side where routes US 50, US 29 and I-66 parallel each other. There is less than one mile between the two outside routes (US 50 and I-66) and consequently no room for an interchange with US 29.

Three parkway routes intersect the Beltway. Two parallel the Potomac River, one on each bank, and carry the same name—The George Washington Memorial Parkway. The one on the Virginia side is a radial route to downtown; the one on the Maryland side is not completed. The other parkway, the principal route between Washington and Baltimore, is the Baltimore-Washington Parkway. None of the parkways are open to trucks and none carry a route number.

These 11 routes account for 13 of the 37 existing interchanges on the 66-mile loop. Two additional interchanges have been provided for in the exit numbering scheme, one of which will be for I-95 on the north side of the loop in Maryland. The other interchange will be used by either the North-Central Freeway or the proposed Northern

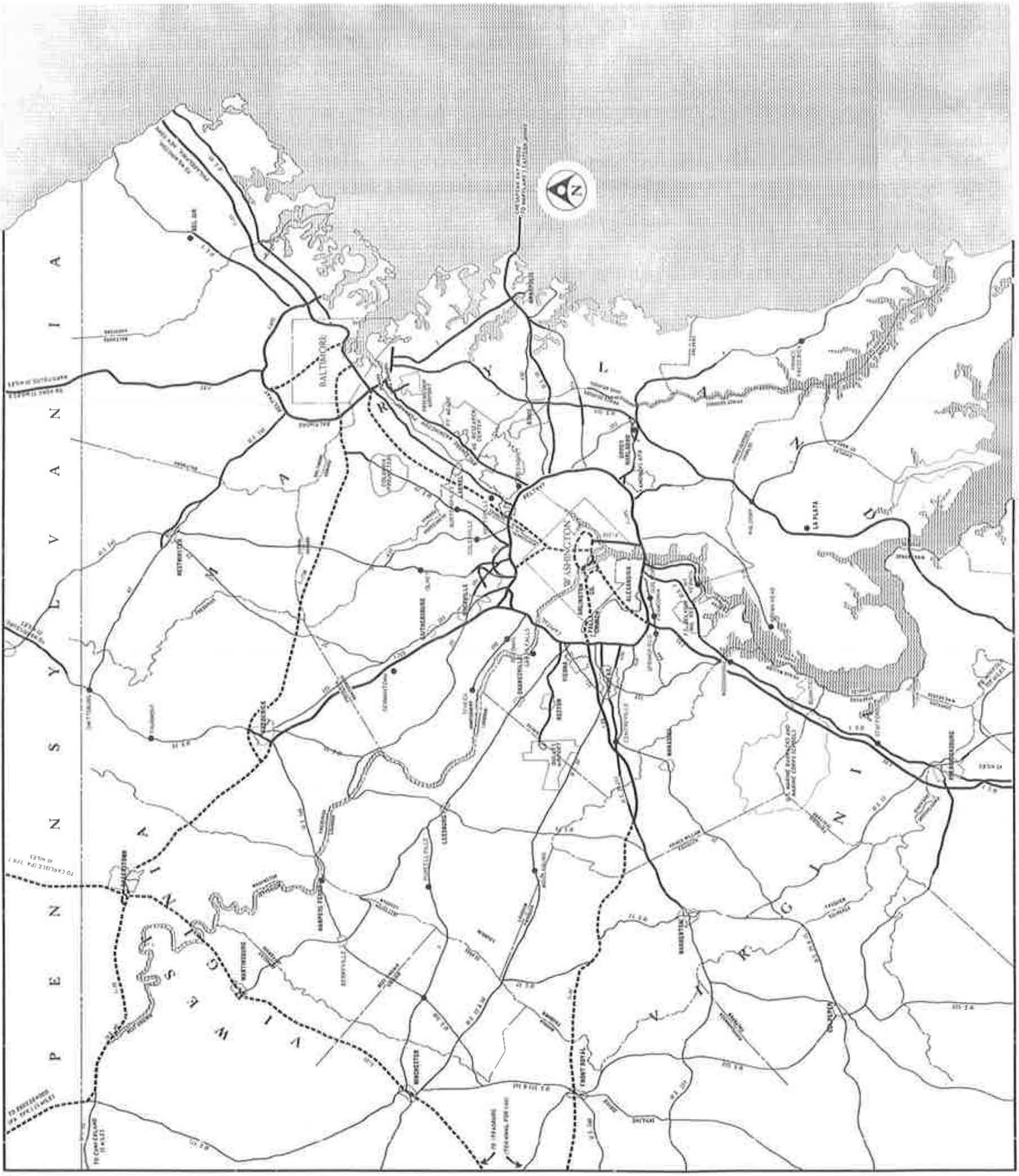


Figure 1. Map of regional highway network.

Figure 2. The Capital Beltway (I-495) and its relationship to Washington, D.C.

Parkway or by both, depending on development of these two proposed systems. Thus, of the total of 39 interchanges, 25 have been allocated to state primary and secondary routes.

The 37 interchanges now open to traffic embrace a wide variety of types and a broad range of signing problems. The most commonly used interchange type is the cloverleaf, but there are some with direct connections, others with collector-distributor roads, a few diamonds and trumpets and 11 where there are ramps missing or the interchange does not otherwise permit travel in both directions between all of its legs. Table 1 gives the number of each type.

In summary, the Capital Beltway, as a laboratory, provides a route which is under the jurisdiction of two state highway departments (except for 800 feet which is in the District of Columbia) and embraces a wide variety of signing problems due to varying interchange types and adjacent land uses.

TABLE I
LIST OF INTERCHANGES ON CAPITAL BELTWAY (I–495) BY TYPE

	Interchange Number	Cloverleaf			Diamond			Direct or Semi-Direct	Incomplete[1]
		Full	Partial	w/ C-D Road	Full	Partial	Trumpet		
VA.	1			X					
	2			X					
	3						X		
	4							X	
	5				X				
	6			X					
	7					X			X
	8			X					
	9							X	
	10		X						X
	11		X						X
	12							X	X
	13				X				
VA.	14						X		
MD.	15							X	X
	16		X						
	17							X	X
	18				X				
	19							X	X
	20	X							
	21	X							
	23		X						X
	24		X						X
	25	X							
	27			X					
	28		X						
	29	X							
	30		X						
	31	X							
	32		X						X
	33	X							
	34	X							
	35				X [2]				
	36	X							
	37A					X			X
MD.	38							X	
	TOTALS	9	8	5	4	2	2	7	11

NOTES:

1. Incomplete is defined as an interchange where one or more of 8 possible turning movements is omitted.
2. More accurately—a split diamond.

Sign Inventory

In order to evaluate the existing signing, an inventory of all guide signs on the Beltway and on each cross route where there was an interchange was conducted between mid-July and mid-August 1965. Several methods to accomplish the inventory were explored. Photography was finally selected on the basis of the accurate reproduction of the messages and their relationship as well as relative size and location of the sign boards. This method was also felt to present the least exposure to hazardous situations, because the photographer could stop his car, take the picture and be on his way again in a matter of a minute or two.

The photographs obtained were enlarged so that the letter height on each sign was a uniform size. They were then collated by interchange and all the signing for a particular interchange spotted on a plan view obtained from either the Virginia State Highway Department or the Maryland State Roads Commission. Figure 3 shows a typical diamond interchange after all the photographs were mounted and the relative sign locations spotted.

Evaluation

Each interchange was then evaluated for conformance to the Interstate sign manual and for agreement with the six principles of signing set forth in a 1958 study of freeway signing in California by Schoppert, Moskowitz, Hulbert, and Burg (1). As for the Interstate signing standards, the signing could be classed as being in reasonable conformance if all the options and alternatives were considered. However, it was also readily apparent that each state had used different alternatives and the uniformity from state to state left much to be desired.

The six principles of freeway signing set forth in the 1958 study are as follows:

1. Interpretation—All possible interpretations and misinterpretations must be considered in phrasing sign messages (words and symbols).
2. Continuity—Each sign must be designed in context with those which precede it so that continuity is achieved through relatively long sections of highway.
3. Advance Notice—Signing must prepare the driver ahead of time for each decision he has to make.
4. Relatability—Sign messages should be in the same terms as information available to the driver from other sources, such as touring maps and addresses given in tourist information and advertising.
5. Prominence—The size and position, as well as the number of times a sign or message is repeated, should be related to the competition from other demands on the driver's attention.
6. Unusual Maneuvers—Signing must be specially designed at points where the driver has to make a movement which is unexpected or unnatural.

The review of the signing on the basis of these six principles pointed up numerous violations which the questionnaire studies later confirmed to be problem locations. The following are examples of some of the kinds of problems encountered.

Interpretation—

1. Two adjacent interchanges, one in Maryland and the other in Virginia, intersect roads with the same name and no indication of the state. Neither road has a route number. (The situation has been partly corrected by removing the road name from one set of signs.)
2. An interchange was signed for Va. 7 eastbound but the motorist was left to discover at the next interchange that there was no exit for Va. 7 westbound. (A supplemental guide sign has now been installed to overcome this situation.)

Continuity—

3. Mileage signs in Maryland use the destination "Richmond" but those in Virginia use "Route 95" to give guidance to the same interchange.

Relatability—

4. Road maps of the Beltway do not show all interchanges or, if the scale is large enough to show interchange ramps, do not show them accurately. This is particularly confusing at partial interchanges.

Prominence—

5. In a few cases, the route name completely overpowers the destination and the motorist is left wondering where his desired exit is.

Unusual Maneuvers—

6. Collector-distributor roads are used at only a few locations and thus become places where unusual maneuvers are required. The distinctions in the signing between these interchanges and the standard cloverleaf are minimal.

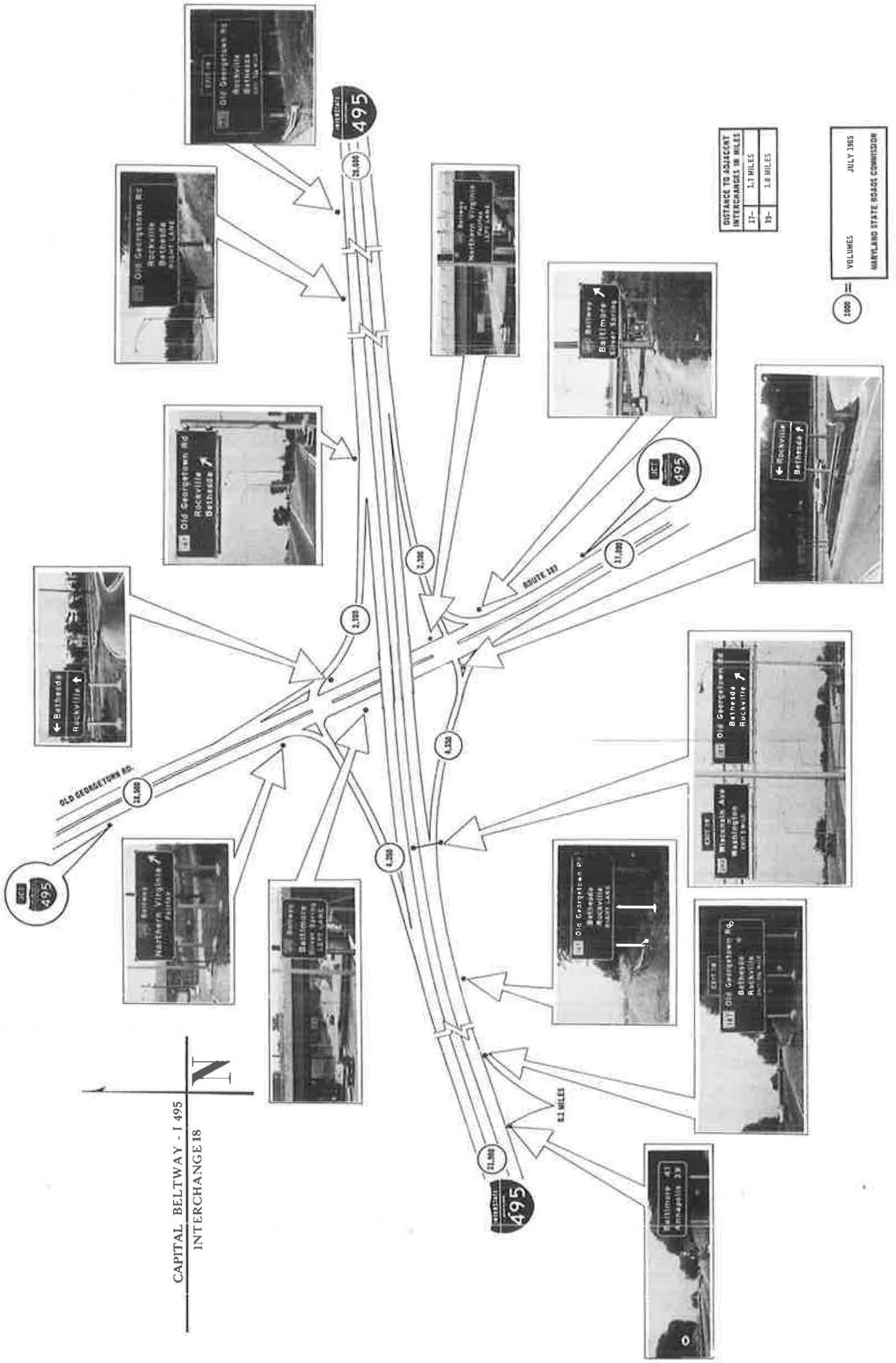

CAPITAL BELTWAY - I 495
INTERCHANGE 18
INTERSTATE
495
OLD GEORGETOWN RD.
ROUTE 187
0.1 MILES
DISTANCE TO ADJACENT INTERCHANGES IN MILES
17– 1.7 MILES
19– 1.0 MILES
1000 = VOLUMES JULY 1965
MARYLAND STATE ROADS COMMISSION
Old Georgetown Rd
Rockville
Bethesda
Beltway
Northern Virginia
Fairfax
Baltimore
Silver Spring
← Bethesda
Rockville ↑
← Rockville
Bethesda ↑
Wisconsin Ave
Washington
Baltimore 41
Annapolis 39

Figure 3.

7. The left exit and entrance are rare events in the same sense as the C-D road, but their treatment does not give the motorist the information he needs to be properly located for his exit maneuver.

STUDIES CONDUCTED

Questionnaire Survey by AAA

Shortly after the project was started, it was learned that the D.C. Division of the American Automobile Association was going to conduct a questionnaire survey on the Capital Beltway. The survey form was to be printed in "American Motorist," the monthly publication of the D.C. Division. The magazine has a circulation of 170,000, with 110,000 of these being heads of households or the principal AAA members. Approximately 37 percent of the readers reside in the Maryland counties and 30 percent in the Virginia counties adjacent to the District of Columbia. The remaining 33 percent are located in the District of Columbia.

An arrangement was made with the editor of "American Motorist" to permit the researchers to review responses to the questionnaire printed in the September 1965 issue of the publication. Figure 4 is a reproduction of the questionnaire.

Survey of Requests for Road Directions by Radio

A national organization of citizens' band radio operators provides emergency aid to persons who call in on their CB radios. The organization, known as Radio Emergency Associated Citizens' Teams (REACT), has a chapter in Washington, D.C., which monitors emergency calls on Channel 9 on a 24-hour basis. Since these units are often mounted in vehicles of all types, they are a convenient means of requesting road directions when the motorist with such a unit becomes lost.

Through the cooperation of the local REACT chapter, a review of emergency call log books was made. This showed a monthly average of 50 direction assistance calls from persons driving on the Beltway. To tap this potential source of information, a mail questionnaire was sent to those persons who made contact between mid-June 1965 and March 1, 1966. Figure 5 shows the letter and questionnaire which were sent. A map was also enclosed for reference. The questionnaire is very similar to the one used in the AAA survey in order to provide comparability.

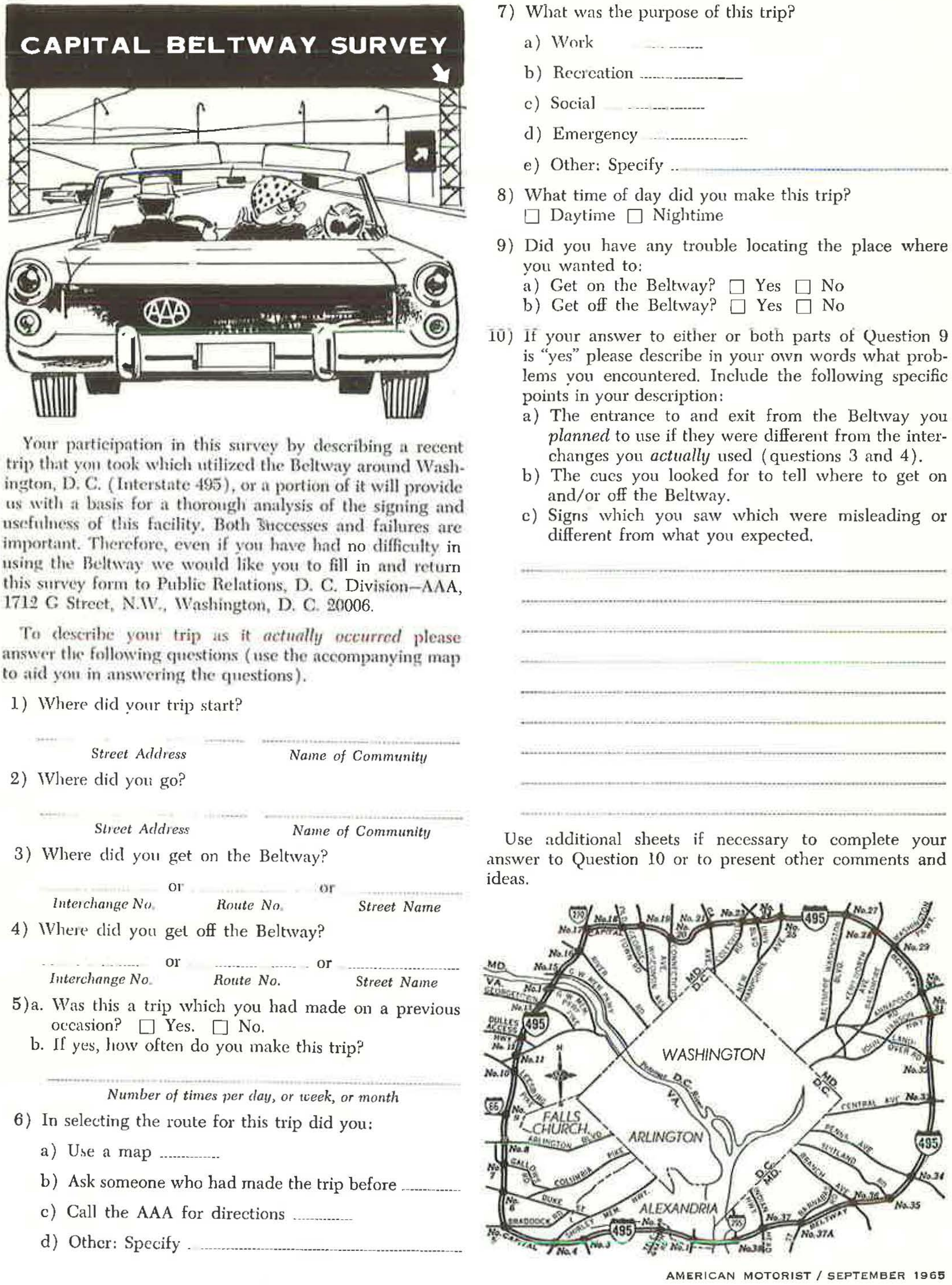
A total of 312 persons were contacted. Of these, 51 lived in states other than Maryland and Virginia, and 44 lived in these two states but more than 10 miles beyond the Beltway. The remainder had local addresses.

Questionnaire and Interview Study in BPR

As the driver survey proceeded, it became obvious that some means would have to be found to contact and talk personally with those who used the Beltway. Several schemes were explored but the complexity and cost of contacting a wide audience which would represent all sections of the metropolitan area were serious drawbacks. Finally, the large concentration of government offices in the District of Columbia triggered the idea of conducting interviews in one of these. It was reasoned that such an office would draw in reasonable proportion to the distribution of population in the metropolitan area. After consideration of what agency might be used, the U.S. Bureau of Public Roads' offices in the Matomic Building in downtown Washington were selected on the bases of easy access and least cost.

The questionnaire shown in Figure 6 was prepared using questions similar to those in the REACT survey and the AAA survey. Four hundred of these were circulated in mid-April 1966 to BPR personnel in the administrative, legal, contract and other divisions which do not have direct responsibility for roadway signing. Figure 6 also shows the cover letter which was circulated with the questionnaire.

Ten percent of the respondents to this questionnaire were then selected for a 20-minute personal interview.



CAPITAL BELTWAY SURVEY

Your participation in this survey by describing a recent trip that you took which utilized the Beltway around Washington, D. C. (Interstate 495), or a portion of it will provide us with a basis for a thorough analysis of the signing and usefulness of this facility. Both successes and failures are important. Therefore, even if you have had no difficulty in using the Beltway we would like you to fill in and return this survey form to Public Relations, D. C. Division—AAA, 1712 G Street, N.W., Washington, D. C. 20006.

To describe your trip as it *actually occurred* please answer the following questions (use the accompanying map to aid you in answering the questions).

1) Where did your trip start?

________ ________
Street Address *Name of Community*

2) Where did you go?

________ ________
Street Address *Name of Community*

3) Where did you get on the Beltway?

________ or ________ or ________
Interchange No. *Route No.* *Street Name*

4) Where did you get off the Beltway?

________ or ________ or ________
Interchange No. *Route No.* *Street Name*

5)a. Was this a trip which you had made on a previous occasion? ☐ Yes. ☐ No.
b. If yes, how often do you make this trip?

____
Number of times per day, or week, or month

6) In selecting the route for this trip did you:
a) Use a map ________
b) Ask someone who had made the trip before ________
c) Call the AAA for directions ________
d) Other: Specify ________

7) What was the purpose of this trip?
a) Work ________
b) Recreation ________
c) Social ________
d) Emergency ________
e) Other: Specify ________

8) What time of day did you make this trip?
☐ Daytime ☐ Nightime

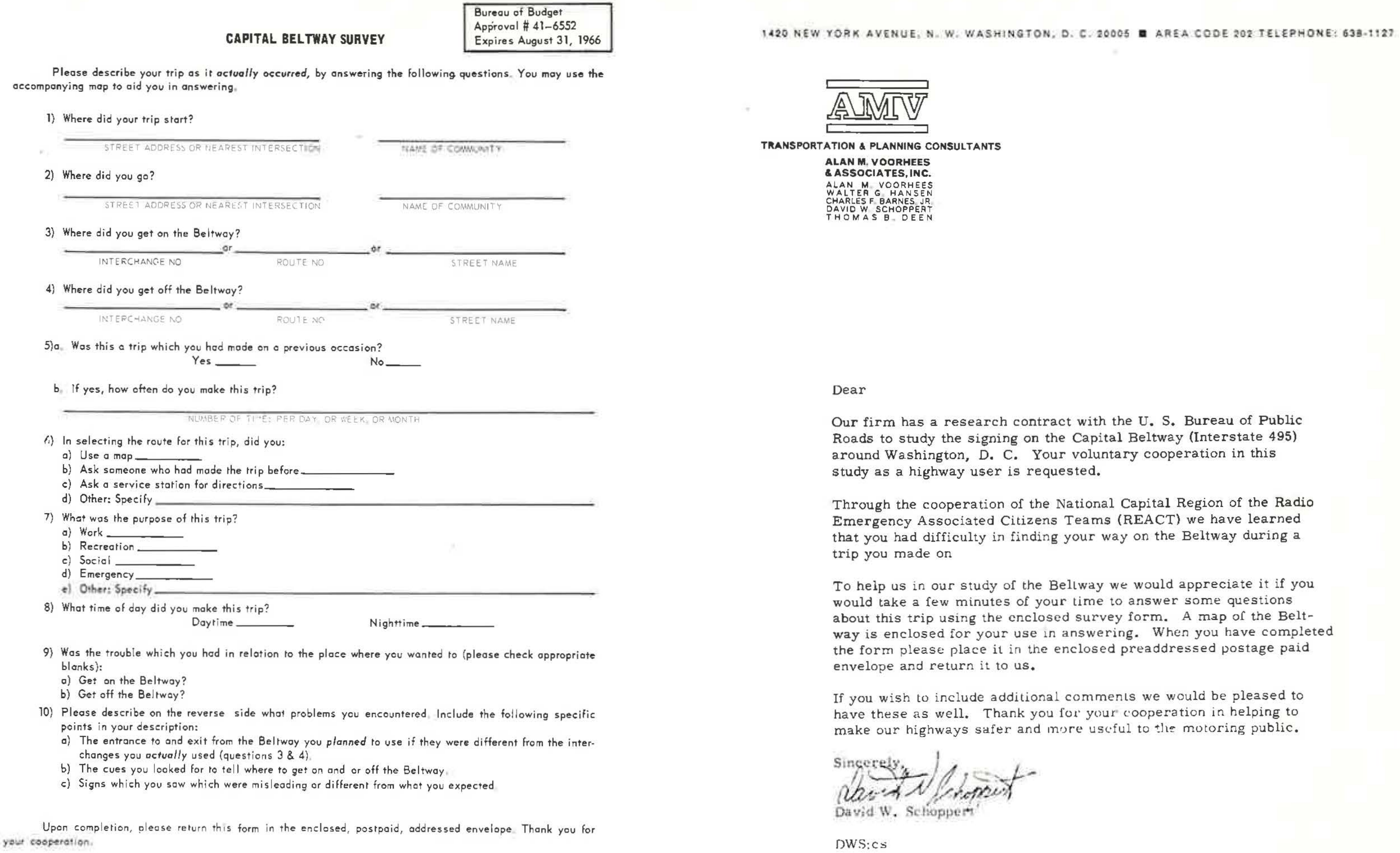
9) Did you have any trouble locating the place where you wanted to:
a) Get on the Beltway? ☐ Yes ☐ No
b) Get off the Beltway? ☐ Yes ☐ No

10) If your answer to either or both parts of Question 9 is "yes" please describe in your own words what problems you encountered. Include the following specific points in your description:
a) The entrance to and exit from the Beltway you *planned* to use if they were different from the interchanges you *actually* used (questions 3 and 4).
b) The cues you looked for to tell where to get on and/or off the Beltway.
c) Signs which you saw which were misleading or different from what you expected.

Use additional sheets if necessary to complete your answer to Question 10 or to present other comments and ideas.

AMERICAN MOTORIST / SEPTEMBER 1965

Figure 4. AAA questionnaire.



Bureau of Budget
Approval # 41–6552
Expires August 31, 1966

CAPITAL BELTWAY SURVEY

Please describe your trip as it *actually occurred*, by answering the following questions. You may use the accompanying map to aid you in answering.

1) Where did your trip start?

_______________ _______________
STREET ADDRESS OR NEAREST INTERSECTION — NAME OF COMMUNITY

2) Where did you go?

_______________ _______________
STREET ADDRESS OR NEAREST INTERSECTION — NAME OF COMMUNITY

3) Where did you get on the Beltway?

_______________ or _______________ or _______________
INTERCHANGE NO — ROUTE NO — STREET NAME

4) Where did you get off the Beltway?

_______________ or _______________ or _______________
INTERCHANGE NO — ROUTE NO — STREET NAME

5)a. Was this a trip which you had made on a previous occasion?
Yes ______ No ______

b. If yes, how often do you make this trip?

____
NUMBER OF TIMES PER DAY, OR WEEK, OR MONTH

6) In selecting the route for this trip, did you:
- a) Use a map ______
- b) Ask someone who had made the trip before ______
- c) Ask a service station for directions ______
- d) Other: Specify ______

7) What was the purpose of this trip?
- a) Work ______
- b) Recreation ______
- c) Social ______
- d) Emergency ______
- e) Other: Specify ______

8) What time of day did you make this trip?
Daytime ______ Nighttime ______

9) Was the trouble which you had in relation to the place where you wanted to (please check appropriate blanks):
- a) Get on the Beltway?
- b) Get off the Beltway?

10) Please describe on the reverse side what problems you encountered. Include the following specific points in your description:
- a) The entrance to and exit from the Beltway you *planned* to use if they were different from the interchanges you *actually* used (questions 3 & 4).
- b) The cues you looked for to tell where to get on and or off the Beltway.
- c) Signs which you saw which were misleading or different from what you expected.

Upon completion, please return this form in the enclosed, postpaid, addressed envelope. Thank you for your cooperation.

1420 NEW YORK AVENUE, N. W. WASHINGTON, D. C. 20005 ■ AREA CODE 202 TELEPHONE: 638-1127

AMV

TRANSPORTATION & PLANNING CONSULTANTS

**ALAN M. VOORHEES
& ASSOCIATES, INC.**
ALAN M. VOORHEES
WALTER G. HANSEN
CHARLES F. BARNES, JR.
DAVID W. SCHOPPERT
THOMAS B. DEEN

Dear

Our firm has a research contract with the U. S. Bureau of Public Roads to study the signing on the Capital Beltway (Interstate 495) around Washington, D. C. Your voluntary cooperation in this study as a highway user is requested.

Through the cooperation of the National Capital Region of the Radio Emergency Associated Citizens Teams (REACT) we have learned that you had difficulty in finding your way on the Beltway during a trip you made on

To help us in our study of the Beltway we would appreciate it if you would take a few minutes of your time to answer some questions about this trip using the enclosed survey form. A map of the Beltway is enclosed for your use in answering. When you have completed the form please place it in the enclosed preaddressed postage paid envelope and return it to us.

If you wish to include additional comments we would be pleased to have these as well. Thank you for your cooperation in helping to make our highways safer and more useful to the motoring public.

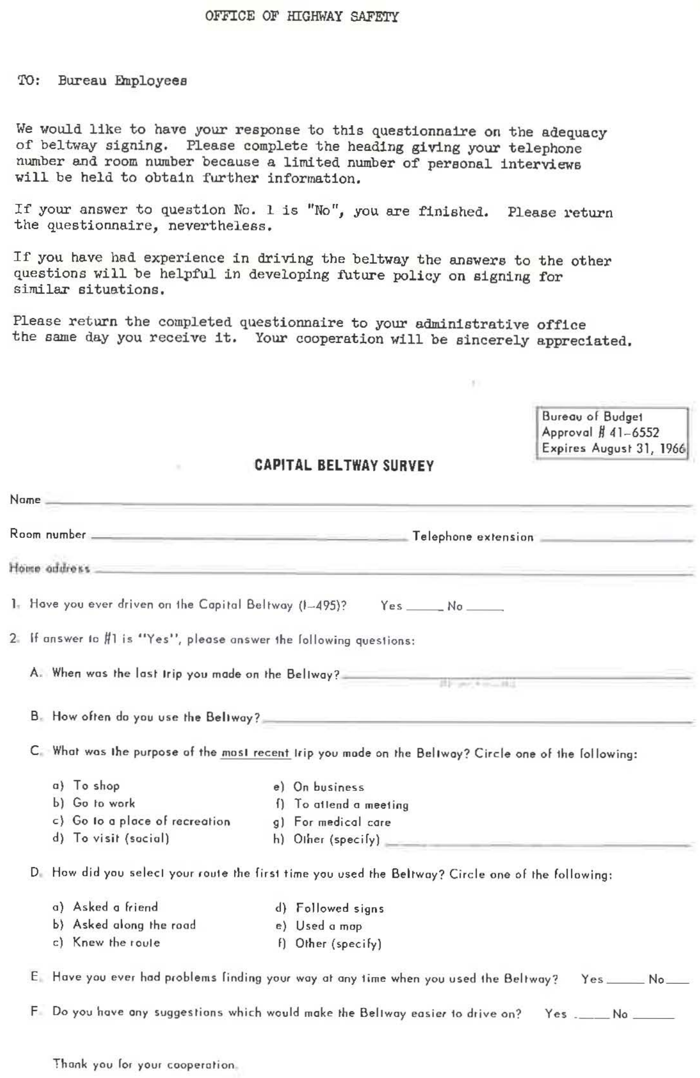
Sincerely,

David W. Schoppert

David W. Schoppert

DWS:cs

Figure 5. Survey form and cover letter used in survey of REACT group.



OFFICE OF HIGHWAY SAFETY

TO: Bureau Employees

We would like to have your response to this questionnaire on the adequacy of beltway signing. Please complete the heading giving your telephone number and room number because a limited number of personal interviews will be held to obtain further information.

If your answer to question No. 1 is "No", you are finished. Please return the questionnaire, nevertheless.

If you have had experience in driving the beltway the answers to the other questions will be helpful in developing future policy on signing for similar situations.

Please return the completed questionnaire to your administrative office the same day you receive it. Your cooperation will be sincerely appreciated.

Bureau of Budget
Approval # 41-6552
Expires August 31, 1966

CAPITAL BELTWAY SURVEY

Name ____________________

Room number ____________________ Telephone extension ____________

Home address ____________________

1. Have you ever driven on the Capital Beltway (I-495)? Yes _____ No _____

2. If answer to #1 is "Yes", please answer the following questions:

A. When was the last trip you made on the Beltway? ____________________

B. How often do you use the Beltway? ____________________

C. What was the purpose of the most recent trip you made on the Beltway? Circle one of the following:

a) To shop
b) Go to work
c) Go to a place of recreation
d) To visit (social)
e) On business
f) To attend a meeting
g) For medical care
h) Other (specify) ____________________

D. How did you select your route the first time you used the Beltway? Circle one of the following:

a) Asked a friend
b) Asked along the road
c) Knew the route
d) Followed signs
e) Used a map
f) Other (specify)

E. Have you ever had problems finding your way at any time when you used the Beltway? Yes _____ No _____

F. Do you have any suggestions which would make the Beltway easier to drive on? Yes _____ No _____

Thank you for your cooperation.

Figure 6. Survey form and covering memorandum used in survey at U.S. Bureau of Public Roads.

Field Observations of Driver Actions

To determine the kinds and approximate number of unusual actions that drivers may be making on a typical day of Beltway traffic, field observers were stationed at selected interchanges on the Beltway over a period of 2 weeks in late August and early September 1965. Two men were stationed at a point where they could observe the entire interchange area. They were instructed to record the action observed, the time of its occurrence, the direction of movement, and the location within the interchange. A typical entry read: "10:45 a. m. —vehicle stopped on shoulder beyond gore in Area H. Driver looked at map, backed up, took ramp H to I."

The letters were used to designate each merging and diverging area so that observations could be translated in the office into specific locations. Where two observed interchanges were close together, an eight-hour observation day was split between them, for example: Interchange A—10:30 to 12:00; Interchange B—1:00 to 2:30; Interchange A—3:00 to 4:30; Interchange B—5:00 to 6:30. Allowance was made for travel time over

TABLE 2

STUDY SITES FOR FIELD OBSERVATIONS

Interchange No.	Route No.	Hours of Observation
1	US 1 (Va.)	3½
4	I-95 (Va.)	5
8	US 50 (Va.)	3½
9	I-66 (Va.)	4
17	I-270 (Md.)	5
19	I-70S (Md.)	6
20	Md. 193	2
23	US 29 (Md.)	3½
27	US 1 (Md.)	3½
29	Baltimore-Washington Parkway (Md.)	6
31	US 50 (Md.)	3½
38	I-295 (Md.)	2
TOTAL	12 Interchanges	47½

local roads and walking to observation points. For a complex interchange where all observations could not be made from one point, a whole day was spent observing different portions of the interchange. Table 2 lists the interchanges studied and the amount of time spent at each one. (Double the time shown to obtain the number of man-hours.)

RESULTS OF STUDIES

"I have no problems now that I have driven the road a few times." This statement was repeated many times both in written comments and the personal discussions which are reviewed in the following paragraphs. It is also a perfect statement of the problem with which this report deals; namely, what is the motorist looking for in roadway signing?

Much work has been done over the years to bring about the present high quality of freeway signing in size of lettering, shape of letters, color, placement, reflectivity and illumination. These achievements are the result of countless tests and observations of driver reactions both in the laboratory and in the field.

The combination of all these elements results in a series of messages which should tell the driver, in such a way as to be understood in a matter of seconds, how to get from place A to place B. On a local road, if the motorist gets lost or makes a wrong turn, he can always ask directions, back up or turn around. On a freeway there is no such readily available information source nor can backing and turning be done indiscriminately and without hazard.

It might be expected that studies of what sign messages should say would be almost as prolific as other technical studies, but such is not the case. Those which have been made have advanced the state of knowledge, but there is still much to be done.

Summary and Comparison of Collected Data

Comparison of the places where deficiencies were noted from the inventory with field observations at selected interchanges showed that inadequately signed locations generated higher percentages of error. Field observation suggests a "normal" level of motorists experiencing difficulty of approximately 0.2 percent of all traffic entering a specific interchange approach. If the number having problems exceeds this level, there is an indication that signing needs review.

Briefly, the three surveys of motorist opinion tapped different strata of users. The REACT survey produced responses which were relatively "earthy" in that there was little effort to analyze the "why" but simply an expression of problems encountered. The BRP study group was not specifically asked for comments but those who volunteered them were more inclined to suggest a solution than to pinpoint a specific problem location. While some were quite knowledgeable about road design, others were typical drivers motivated by a desire to simplify their driving task.

These two groups can be contrasted with the group responding to the AAA survey. This group, possibly because it was contacted within a few months after the Beltway was opened, identified more specific problems than any other group. They also offered numerous suggestions for improvements. The AAA group represented on the whole the opposite end of the spectrum from the REACT group in that most of the respondents appeared to be sophisticated motor vehicle users who were aware of problems and the need for their solution.

The project was mutually aided by each of the three sources of information. Findings in each group supported information gathered in the others and together they generated in the researchers a feeling for the freeway signing needs and wants of motorists.

Simply expressed, the freeway driver who is not familiar with the route is seeking guides that will orient him to fixed points which he recognizes. Losing this contact may cause erratic actions or an incorrect turnoff. Interesting data (beyond the scope of this study) on driver behavior as an effect of signing could be obtained from comparisons of freeway drivers in areas with which they are familiar and areas with which they are not.

As was noted previously, some of the data collected in the three studies were identical. This information is summarized in the following paragraphs, after which findings unique to each study are presented.

Percent Reporting Problems

Fifty-two percent of the BPR group reported difficulty in using the Beltway. This compares with 43 percent of the AAA group who reported problems. The higher percentage in BPR could be a result of six months' additional driving experience in which to identify problems on the Beltway. In both cases, this is a large proportion to respond YES to the question, "Do you have any problems in driving the Beltway?"

In the case of the REACT group, these were preselected and only persons who had problems were contacted.

In response to a question about whether the problem was leaving.or entering the Beltway, 73 percent of the REACT group indicated it was leaving, 12 percent entering and 15 percent both. In the AAA survey, these figures were 50 percent off, 37 percent on and 13 percent both. The relatively small size of the REACT sample could have had an effect on these percentages but they still reveal that the most serious area of concern was how to leave the freeway.

The BPR group was not asked to classify the location of their problem.

Division of Responses by Jurisdiction

A review of census information shows that the population in the Washington, D.C., Standard Metropolitan Statistical Area is distributed among the three jurisdictions as shown in Table 3. Also shown are the percentages of responses from each jurisdiction in the three surveys which were made.

Because of long-range plans to move BPR into Virginia, there is some bias in the response from this group to Virginia. However, the AAA response is slightly heavier in Maryland when compared to the SMSA population. The REACT group's base radio station is located in Maryland and thus it is logical that these returns would have a strong bias toward this state. However, the relative number of REACT responses was so small that overall it can be stated that the total of all samples was representative of the population outside of the District of Columbia. The small return from D.C. was expected based on the limited usefulness of the Beltway to central city residents.

TABLE 3

PERCENT DISTRIBUTION OF RESPONSES BY JURISDICTION, ALL SURVEYS

Jurisdiction	SMSA	BPR	REACT	AAA
Maryland	35	36	70	55
Virginia	27	48	10	33
D.C.	38	16	20	12
Excluding D.C.				
Maryland	57	43	88	63
Virginia	43	57	12	37

Frequency of Use

A comparison of Beltway usage between the BPR groups and the AAA groups shows that while daily trips are approximately equal (14% vs 19%), there are only half as many in the BPR group who classify their usage at less than once a month. On the other hand, twice as many in the BPR group use the Beltway several times each week as did the AAA group. The REACT sample was too small to be meaningful in this comparison.

Trip Purpose

The predominant trip purpose among all three study groups was social-recreation, with percentages ranging from 62 to 69. Work was the second highest with 24 percent in two cases and 19 percent in the REACT group. This latter figure compares with the 1955 Transportation Study which showed work accounting for 41 percent of the automobile trips in the Washington area.

Route Selection

A question which was asked of all three groups was the means used to select the route used on their first trip on the Beltway. Among the BPR respondents 38 percent reported using a map. This compares with 47 percent in the REACT group and 56 percent in the AAA survey.

The number asking for information varied widely ranging from 9 percent for the BPR group, to 20 percent for the AAA survey to 37 percent for the REACT respondents. The other items within each group are not comparable due to variation in tabulation but it is interesting to note that when specifically suggested as an alternative, 26 percent of the BPR group chose "Followed Signs" as their means of route selection.

AAA Questionnaire

The most significant benefit from the AAA questionnaire was obtained from question 10, which asked for comments. Eighty-four percent of the 520 responses contained comments about some aspect of the Beltway. These ranged from brief comments to detailed six-page handwritten critiques. Constructive comments far outnumbered those that could be classed as "sour grapes." In analyzing the comments, only those which pertained to the signing were selected and catalogued under the following headings:

1. "Signs are poor; not enough advance warning."
2. "Signs are confusing."
3. "________ (a specific location) is not included on the signs."
4. "The names of distant cities are misleading; more local names should be used."
5. "The names of local places are meaningless to the stranger."
6. "Incomplete interchanges should be marked."
7. "When interchanges with important routes are omitted, signs should indicate alternate routes."
8. "There is need for specific distinctions between interchanges with two exit points and those with only one."
9. "Roads with similar names cause confusion."
10. "More trailblazers are needed to direct motorists to the Beltway."
11. "Exits which are 'poorly' designed need special signing."

The locations mentioned most often by motorists were compared to the locations that were inadequate in regard to the principles described earlier. In every case there was a violation of principles and the motorists' comments confirmed this. The specific problems thus described were most helpful in formulating the concepts and criteria set forth later.

Cues Used by Motorists

Question 10 on the AAA survey also asked drivers to state cues they sought when driving. A relatively small number responded with a specific answer but these disclosed some interesting relationships.

The cue most mentioned was "Exit Number" with a total of 15. Route name was second with 11 mentions, and then route number and place names, with 8 and 7 mentions, respectively.

Eight persons found cardinal directions to be useful cues but six wanted to use clockwise and counterclockwise on the Beltway. Four suggested a stylized map on the approach to the Beltway might be helpful. On the other hand, 13 commented that cardinal directions on a directionless loop were confusing. (Virginia uses the cardinal direction on its Beltway signing; Maryland does not.)

Survey of Requests for Road Directions by Radio

Approximately 25 percent, or 85 returns were received from the mailed questionnaires. However, this total included 19 returned as non-deliverable and 17 from people who could not recall the problem they had or who were REACT members who called in to help motorists without radios who were in difficulty. The latter group did not recall the specific incident in enough detail to report on it. Thus, there were 49 usable responses, about 15 percent of the sample.

This survey was able to contact both strangers and local residents. Several comments were common to both groups, such as: (a) partial interchanges cause a problem; (b) maps do not show interchanges clearly; (c) when exit numbers are used, they should be repeated on each sign in a sequence; (d) travel speeds are too high for the road; and (e) there is not enough advance warning. Although not specifically stated, there was noticeable feeling of anxiety among many of those who responded to the questionnaire.

Beltways, like many urban freeways, have relatively short average interchange spacing compared with rural freeways. Thus, several people spoke of the lack of advance warning and the need for an advance sign two miles from the exit ("Like on the New Jersey Turnpike"). This is impossible on the Beltway in many places. Also, there were complaints of high speeds and lack of time to make decisions. A rural freeway driver is conditioned to a fairly long interval between interchanges, giving him time to recover from decision-making processes concerning the previous interchange. On an urban freeway, these decisions must be made as often as every 60 seconds and in some places on the Beltway within 45 seconds. For a driver who does not use the Beltway frequently and is not thoroughly familiar with its interchanges, this appears to be a decision-making rate approaching his capacity under the existing system of signing. This system does not provide a continuum of information, but rather individual pieces which must be processed for each interchange.

Other Comments

There were numerous other comments among the 33 persons reporting difficulty on the Beltway. In addition, several suggestions were made for such things as rest areas with maps, pictorial signs of the Beltway, additional roadway lighting, telephones, and more overhead signs. As in the AAA survey, the responses were generally constructive and indicated appreciation of the Beltway as a useful new road.

Questionnaire and Interview Study in BPR

Response to the questionnaire portion of the BPR survey was excellent. Within two weeks, 337 responses had been returned. Approximately 25 percent of the respondents made written comments about many aspects of the Beltway even though comments were not specifically requested. A total of 75 comments were received on signing, and 65 on other aspects ranging from speeding through design features to maps. In the latter group, 13 comments were received dealing with some aspect of speed such as slow traffic keep right, minimum speeds, or that speed is too high for the traffic. Another 38 comments dealt with various design features of the road, with lane drops, both at pavement width transitions and at interchanges, being mentioned most often. Inconsistency of interchange types and driver inability to identify the type being approached were mentioned in 8 of the 38 comments on design features. Several respondents suggested the need for improved maps and urged that exit numbers be shown on all maps.

Of the 75 comments directed specifically to signing, approximately one-third dealt with problems at specific locations. All dealt with the same locations mentioned in the AAA survey, but each location was only mentioned a few times since comments were not specifically requested. No new locations were mentioned. Another 40 percent of the comments on signing were directed to the messages used. Again, depending on the point of view, comments on place names suggested that strangers needed more distant points; area residents needed more local names; and a third group felt that there were too many local names. Among those who use exit numbers, there were several suggestions for consistent and complete placement of such numbers if they are to be used.

Cardinal directions was the subject of about 12 percent of the comments on signing. Some said, "Do not use on a beltway." Others said they should be used, and a few suggested clockwise and counterclockwise in place of cardinal directions.

The remainder of those who commented (about 12%) summarized their feelings in the phrase, "Not enough advance warning." The phrase is most puzzling because it tells nothing of the real problem. However, a better idea of what was meant was obtained in the personal interviews which are described next.

The Personal Interviews

Approximately 10 percent of those who returned a questionnaire were requested to have a personal interview. The researchers were permitted to use a desk in the BPR offices and over a two-week period contacted 33 persons for a 20-minute personal interview. The interview was unstructured and each person was encouraged to describe the problems he or she had while driving on the Beltway. Often in describing their problems, general suggestions were made after which the interviewer tried to obtain specific comments on the portion of the sign message which was most helpful, the understanding of cardinal directions and preferences in regard to sign location.

In selecting interviewees, a larger percentage of women were included than actually responded to the questionnaire. Maryland residents had fewer comments than Virginia residents, and thus fewer of the former were included in the sample. The characteristics of the sample are as follows:

Total Interviewed	33
Men	23 (70%)
Women	10 (30%)
Maryland Residents	9
D. C. Residents	3
Virginia Residents	21

Interview Responses—Face-to-face discussion with actual Beltway users was a most useful adjunct to the study. Some of the categorical phrases which had been seen only in written form began to take shape, and a feeling for some of the more basic problems on the Beltway was developed as interviews progressed.

Phrases such as "Not enough advanced warning," and "Speeds are too high" are the only way that the layman can describe his feelings of insecurity as he drives a portion of the Beltway with which he has little or no familiarity. In short, it becomes obvious that the close average spacing between interchanges on an urban freeway creates a need for driver decisions at a much faster rate (as often as every 45 seconds in some places) than required on other limited access highways.

Because of this need to make a continuing series of decisions at a rapid rate, those drivers who are on an unfamiliar section of a freeway are looking for aids to their orientation. They want the kind of orientation they get when they have a two-mile advance warning of an interchange, plus a distance to the next interchange—almost like a map unfolding in front of them as they drive; something which they can relate to a map if they are using one.

In contrast to this desire, we find that present Beltway signing is like a series of insulated cells, with no message continuity. Thus, a driver has no way to prepare for decisions several miles in advance but must pass through several closely spaced interchanges, each of which has to be processed on an "Is this the one I want?" basis. It is understandable that drivers desire unenforceable low speed limits or ask for "more advance warning."

On the basis of interviewee desire for more orientation, as well as the number of written responses with the same implication, study recommendations will urge expanded application of signing to provide the desired orientation.

Other more specific information was also obtained from the interviews. One example of this was the way in which drivers combined the cardinal direction and place name. Even though there is a distinction in letter style and size, many people did not recognize this distinction, and would read the message "Rt. 7 EAST—Falls Church" as "Rt. 7—East Falls Church." Because there is an East Falls Church, not reached by using Rt. 7, the sign creates immediate confusion in the minds of some motorists. The use of words like "to" and "and" was suggested to separate cardinal direction and a place name.

There was another, smaller group who used the phrase "not enough advance warning" to criticize the location of overhead "gore" signs. To these people a gore sign which is actually mounted in the gore provides final information too late in comparison to a gore sign which is over the road several hundred feet in advance of the exit ramp nose.

Another desire was for uniform marking of the gore with a sign such as the presently used EXIT sign. Both written and verbal comments indicated that some drivers use this sign as a definite indication of exit nose location. However, present practice is to omit this sign in certain situations, particularly where there is an overhead sign in advance of the gore.

One of the problems dealt with in the interviews was the kind of information drivers use in deciding what exit to use. As was found in the California study, drivers want a mix of information which varies not only on an individual basis but with the same driver in different situations.

Drivers generally use signs to only a limited degree when in familiar surroundings; but, as travel extends to the metropolitan area, they rely primarily on route names and/or place names. Women seem to prefer place names over all other information. Men will use either place names or route names, whichever is convenient. In neither case is much attention given to cardinal directions. Women, in particular, claimed little compass orientation.

Knowledge and use of route numbers were more limited than for either place names or route names, particularly for state route numbers. However, Interstate system numbers and major US route numbers were fairly well known, particularly those routes within the interviewees' states. It appears then that the Interstate Highway System is generating an awareness of a number of freeway routes.

A few of those interviewed suggested that symbol signs would be helpful; others said identifying every road crossing, whether there was an interchange or not, would aid in area orientation.

Field Observations of Driver Actions

A total of 453 unusual actions were observed in 95 man-hours at the 12 interchanges studied. This can be considered a minimum number of observed actions because there were locations where even two men could not observe the whole interchange and it was possible to miss one action while another was being observed. The types of actions observed and the number recorded by location on the Beltway or local road are shown in Table 4. The number at each interchange is also shown in the table. Note that there is considerable variation from one location to the next.

The pattern observed indicates that the technique of field observations can be used to obtain a relative measure of signing effectiveness. By relating the number of usual maneuvers to the volume of traffic entering the interchange, a problem approach quickly stands out from the others. Useful information was obtained from observation periods as short as two hours. The success of this approach strongly suggests the need for further research in depth to explore these relationships.

The percentages of a single approach related to all the other approaches taken as a group are plotted in Figure 7. A definite break appears above 0.2 percent. Thus, it is safe to assume for the data collected in this study that 0.2 percent of the drivers using any approach will have problems requiring an unusual action. However, when the percentage exceeds this level, the signing should be studied in depth to see which principles are being violated. In the case of the approaches which are above 0.2 per-

TABLE 4

TYPES OF UNUSUAL DRIVERS' ACTIONS OBSERVED IN FIELD

Type of Action Observed	Number of Observations		
	On Beltway	On Local Road	Total
Swerved, weaved, or hesitated to enter an off ramp	68	28	96
Stopped and backed up	37	47	84
Stopped and cut across gore	—	27	27
Stopped, read map, then proceeded	38	29	67
U-turned—at a cross street on local road	—	135	135
—across median	5	8	13
—using interchange	7	3	10
Crossed a divider between ramps	2	6	8
Continued all the way through a collector road	13	—	13
Totals	170	283	453

Interchange Number	Number of Observations		
1	55	23	78
4	24	25	49
8	4	13	17
9	19	0	19
17	8	Not observed	8
19	6	90	96
20	2	0	2
23	5	34	39
27	19	21	40
29	22	64	86
31	6	11	17
38	0	2	2

cent, each one has problems which a careful review in relation to signing principles shows to be correctable.

The previous tabulations show that, although there are some differences among the three questionnaire surveys conducted, data trends were all in the same direction. Thus, it was felt that the information acquired from each was valid and the impressions from each were merged to develop the conclusions in this report.

MEETING OF EXPERTS

One of the unique phases of this study was a seminar of prominent traffic authorities to study and critique the information which had been collected. The meeting was held December 13 and 14, 1965, in Washington, D.C. Those participating were: C. S. Carmean, Traffic Engineer, Iowa State Highway Commission; M. J. Hartigan, Assistant District Engineer, Illinois Division of Highways; C. J. Keese, Executive Officer, Texas Transportation Institute, Texas A and M University; J. O. Morton, Commissioner, New Hampshire Department of Public Works and Highways; A. R. Pepper, Traffic Engineer, Colorado Department of Highways; and J. E. Wilson, Traffic Engineer, California Division of Highways.

The plan of the meeting was to provide the six experts with an overview of the facility under study and then draw from them points of agreement and disagreement as to the criteria which should govern freeway signing in general and beltway routes in particular. Therefore, the first item on the agenda was a clockwise tour of the entire Beltway including several interchanges of varying types. In place of a prepared commentary, the group preferred to use commonly available road maps. Destinations were selected which they then tried to reach mentally by following the signing. The commentator then explained points which were in question.

After the tour, the group split into two subgroups. One group dealt with "on-route" signing of a beltway route. The other group considered signing approaching a beltway on any crossroad which interchanged with it.

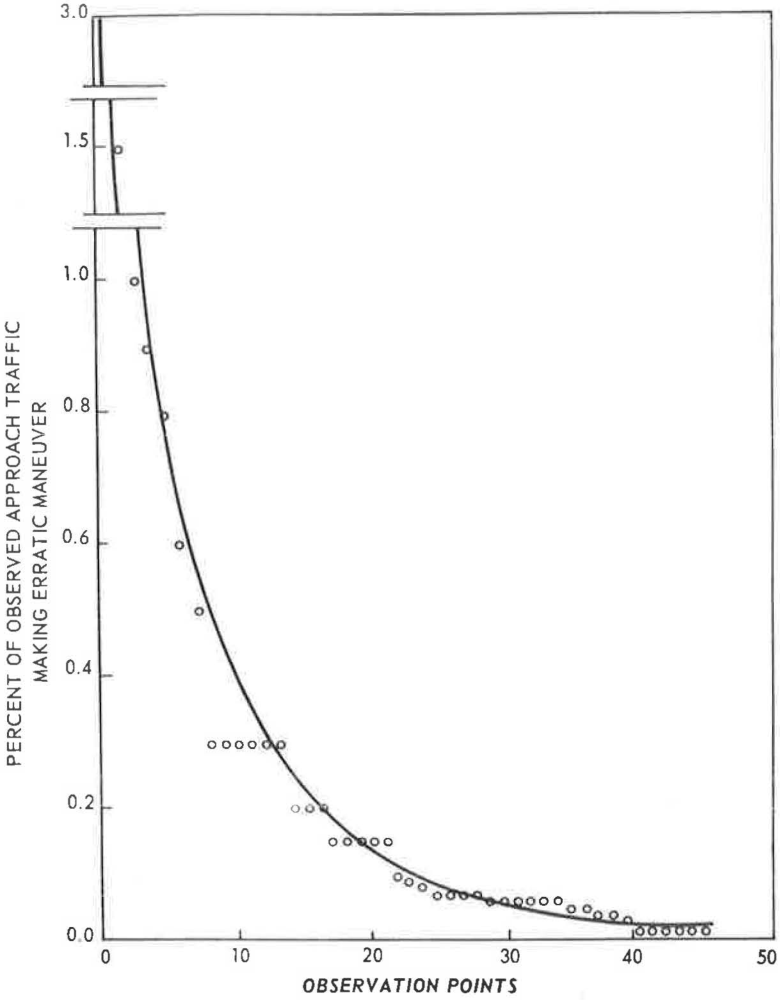


Figure 7. Variation in observed traffic behavior.

The group then reconvened, discussed the conclusions reached separately and unanimously set forth the following summary statements:

1. Guide signing should lead the driver along a route, or series of routes, in such a way that it confirms and supplements trip planning based on other information, such as road maps.
2. As a corollary to signing which confirms and supplements trip planning, maps should be prepared which are as accurate as possible, particularly where interchange detail is shown. A map which shows interchange ramps that do not exist, or route names that disagree with the signing, can create impossible decision-making situations. Roadside rest areas on both beltway and radial routes can be used to display official large scale state maps; these can give the motorist an overview of both the highway system he is on, and the one which he is approaching.
3. There are two distinct classes of guide signing required by the motorist—orientation guide signs and interchange guide signs. Orientation signing should not be included in the interchange sequence and should be differentiated both by its lateral and linear position with respect to the traveled lanes. As used here, orientation refers to signing which helps the motorist locate himself, gives him a target destination at

which to aim, or confirms a decision just made. The elements of the orientation signing series would not be new but would consist of present mileage, confirmatory route marker, through lane and interchange sequence signs. However, recognizing orientation and interchange signing as two distinct classes permits achievement of more consistent design and installation.

4. For a route forming a closed loop and carrying its own route number, mileage signs should show route numbers and names of major intersecting radial routes rather than off-route place names. On a beltway the place names which can be used on the mileage sign fall into two classes—those of major cities some distance from the area which the beltway encircles and those of relatively small and unknown satellite communities around the urban center. If other major cities are used, the motorist may not be prepared to change routes to reach them. If satellite cities are used, they are of little value to the stranger. Thus, because route numbers and names are the foundation of trip planning, route numbers were suggested so that the motorist may orient himself in relation to the highway system.

5. Orientation for motorists approaching a beltway should begin several miles from the interchange. The distance would be dependent upon the class of route but on an important radial freeway, it could be as much as 10 miles. The amount and kind of information presented should be dependent on radial route classification and should convey the fact that the beltway is a closed loop. However, means of portraying the closed loop concept need further study. Whenever possible the signing should also lead the motorist to a more important highway system than the one he is on, e.g., from secondary to primary to Interstate.

6. Signing must be done on a system basis rather than on an individual interchange basis and must extend beyond the right-of-way of a specific facility. If this concept is followed, interchange design will include signing. Or, stated another way, design of the roadway and the signing must progress together in order for the completed highway to fully serve the motorist.

Specific criteria for signing freeways in particular, but which are equally applicable to all road systems, were discussed throughout the meeting. The following statements present in summary form the points on which there was unanimous agreement:

1. The information presented on a sign can be ranked in the following order of importance: (a) Route Number, (b) Route Name, (c) Cardinal Direction, and (d) Place Names. Rather than "permit" the use of all categories, only the first one or two items should be standard. Additional items of information should be added only if the desired alternative is not clear, in which case, an item would be added until it was. The same classes of information should be provided to motorists on all routes regardless of route classification. If standard items are limited to route name and number, it would be expected that greater use would be made of supplemental guide signs in the interchange signing sequence.

2. At no time should the driver face more than two choices at a decision point. These choices may be between two route numbers, two route names, two cardinal directions, right or left, or two place names, but for each item of information presented for one choice, there should be a comparable item for the alternative. If true comparability is not possible, the clearest alternatives should be selected.

3. A cardinal direction should be used only in situations where it represents true direction. On a beltway or at locations where the direction would cause confusion, it should be dropped and another item of information used to give directional orientation if required.

4. A sign bearing an important place name either along the route or at the route terminal should be used at the gore rather than "Thru Traffic." On a beltway, the place name would be replaced by the number and/or name of the route.

5. There is need for a consistent distinction between interchanges with one and two exits. Steps to achieve this are: (a) On interchange sequence signs, show two distances for two exits. For example:

River Road East—1¼
West—1½

(b) On advance signs change EXIT to ONE EXIT and EXITS to TWO EXITS; (c) On interchange signing, do not show cardinal directions when there is a single exit; (d) if exit numbers are used, supplement them with a letter designating cardinal direction for each ramp where there are two exits. If there are more than two exits or two exits with the same cardinal direction letter, use other letters such as A, B and C instead of N, E, W, S.

6. Arrows can be useful in guiding motorists. Down arrows should be used only for lane assignment. Upward sloping arrows are used for ramps which are not extensions of the through lanes. Where the ramp makes a severe turn, the slope of the arrow should be exaggerated to show this.

7. More extensive overhead illuminated signing should be required on urban freeways and approaches to achieve better assignment of traffic to lanes.

8. Locating substantial signs and their supports in the gore creates unnecessary hazards. All signs, except possibly an EXIT sign on a break-away post, should therefore be located in advance of the gore.

9. Sequence signs should identify the next three interchanges, including route number, route name, exit number, if used, and mileage to the nearest quarter mile.

10. Mileage signs should be permitted to carry three lines of information.

11. A trailblazer symbol combining the standard route shield and the word "beltway" would be useful both on and off the route.

The group believed that present signing of freeway routes, with refinements such as greater use of the interchange sequence sign, would provide adequate information. In fact, it was the consensus of the group that if a motorist becomes confused with only a few elements of information, the addition of more signing elements would only confuse him further.

The present standards with modifications discussed previously can be applied to beltway routes with a minimum of difficulties. The most crucial problem, however, and the one for which the group did not have an answer, is how to sign a radial route which interchanges with a beltway route. (The reverse problem of signing from the beltway route to a radial or linear route can be handled with present standards as modified.)

Motorists approaching a beltway route on a radial can be classified logically as (a) those whose destination is the central city; (b) those whose destination is some distance beyond the beltway and who are outbound from the central city, or who wish to bypass the central city; and (c) those whose destination is around the periphery of the central city in the area served by the beltway. Each of these groups is seeking a different kind of information but it is extremely difficult to include it all in an interchange signing sequence. However, on the basis of what is presently known, elements which can be excluded have not as yet been identified.

The panel spent a portion of its time discussing the pros and cons of symbolism on highway signs both for directional orientation at an interchange and on trailblazers leading to various facilities. There was agreement that there are known instances where interchange symbol signs have been effective. However, there was a reluctance to state at this time that symbols would resolve some of the difficulties discussed previously. The panel strongly supports additional research on the use of symbols at interchanges.

In contrast to the lack of enthusiasm for symbols at this time, there was strong support for unique trailblazer symbols for the Interstate system. Trailblazers could be used to lead people to the system and could then be used on the system to alert people to unique elements of the system such as a beltway.

CONCLUSIONS

The merging of the data collected in this study with the work done previously in California and the opinions of the experts has led to three basic concepts for signing beltways in particular but which have application to freeway signing generally. From these concepts, it is possible to establish rather specific criteria for the use, location and message of each of the eleven elements which make up a complete freeway signing package. Some of the most significant of these are given at the end of the discussion of the concepts.

Signing Concepts

Concept 1—Provide orientation through the consistent application of a series of sign elements which will provide sequential and confirmatory information for the motorist.

The evidence gathered for this report points strongly toward the need for an element within the framework of freeway signing which will keep the motorist consistently informed as to what lies ahead. The individual interchange approach to signing does not suffice in areas where interchanges are closely spaced and the decision-making rate is correspondingly rapid.

On a rural freeway, the motorist usually has several miles between interchanges to determine the appropriate exit. In contrast, on an urban freeway it is not infrequent to find interchanges are passing by quicker than decisions can be made. Drivers who must rely on signing for directions are generally unable to gage their position with any precision. When interviewed about their needs in these situations, they consistently ask for "more advance notice."

A word which better describes this motorist need is orientation. It has been used before in highway signing work, but not in the sense that it represents a package of information which is used consistently at every interchange and which answers the following questions:

1. Where am I now in relation to the interchange I am seeking, and what is its configuration?
2. If this is not the interchange I want, where are the through lanes at this interchange?
3. If this is the interchange I wanted, did I take the right road when I turned?

What kind of signing is required to provide orientation? Actually, all the elements of an orientation series of guide signs exist now, but the pieces have not been related to each other to form a consistent pattern. The key element is the interchange sequence sign (Fig. 8) which provides distances to the next three interchanges in such a way that the motorist knows at a glance his progress toward a desired interchange.

The other elements of the package are the mileage sign showing distances to major points, the route confirmation marker, and the through lane sign used at the gore of some interchanges. Outside of the interchange areas, orientation would be fostered by a consistent policy of naming road crossings, prominent topographical and geographical elements, and political boundries.

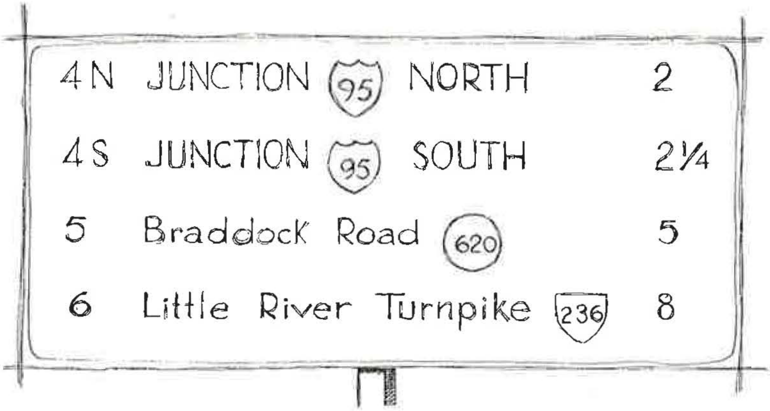


Figure 8. Typical interchange sequence sign showing use of exit numbers.

On freeways with close interchange spacings, one or more of these three signs (mileage, route confirmation, through lane) are often omitted because of lack of space between interchanges. However, there is no prescribed pattern which should be followed in deciding which to omit and which to include. Thus, the first concept is to provide an orientation guide sign series which is consistently applied to each interchange on a freeway and which creates a common thread running through all interchanges, and to further identify intermediate points which will help a motorist to locate himself along his route.

Concept 2—Establish route numbers and route names as the primary elements of interchange guide signs and reserve the use of place names for selected locations where they give the motorist directional orientation which could not be otherwise provided.

As has been found in previous studies, the data gathered on guide sign messages indicate that a motorist operates on a mixture of route name, route number, and place name information, depending on his location in relation to his most traveled routes. However, it also appears that, when required to do so, he can do a reasonably good job of finding his way by using road names and route numbers. Either one may be used, but road names are generally more familiar than state route numbers to the motorist who is reasonably familiar with his surroundings, while strangers to an area find that route numbers are most useful. Some US route numbers and the Interstate System routes appear to have fairly widespread recognition among all classes of motorists.

Place names, particularly in an urban area, are useful to many motorists, but cannot begin to depict all the places that may be reached from a particular interchange. The data collected from the motorists contacted for this study indicate that place names never really satisfy anyone. A name which is suitable for one person does not suit the next. It is soon learned that there is no "right" name. Furthermore, names of numerous local communities often create confusion for the stranger who is seeking only route numbers.

It appears that the situation in signing urban freeways is much the same as that for the city street system. It has long been recognized as unfeasible to indicate at each cross street along a particular route all the streets in each direction from the intersections. The motorist must, therefore, at least learn the street name he is seeking. Likewise, when using a freeway, he should be seeking a particular road from which his destination may be reached. This tailoring of route selection to individual needs is often required because the interchange selected by the authorities for a particular place may only serve to confuse a person seeking a destination which is best reached by using a street in the next municipality.

This concept envisions a gradual elimination of most place names from freeway signing. Some of the routes intersected along a freeway will lead to major places some distance away, and the use of a place name serves to give quickly recognizable directional information for all classes of motorists. These places may be either the terminals of the route or major places on the route. In the area served by the freeway there may also be places which are best reached from a particular interchange. These, too, could be included on the guide signing, provided they are readily identifiable, and also give useful directional orientation.

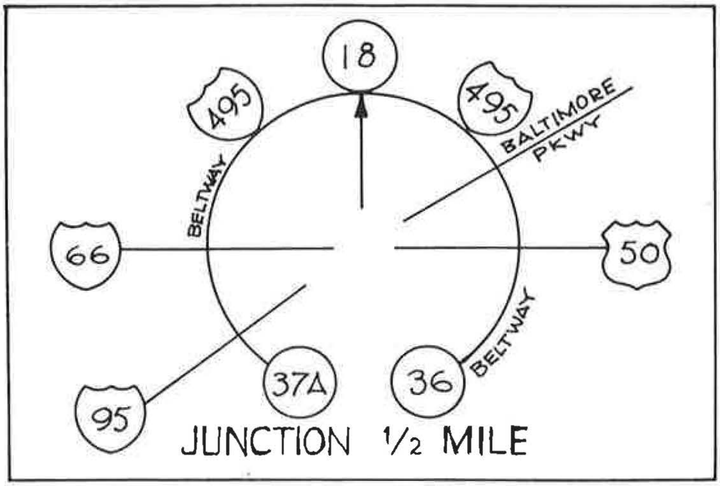
If public policy decrees that place names be provided for every interchange, supplemental place name signs with appropriate exit information could be used rather than repeating a name several times on the primary guide signing.

In time, it is reasonable to expect that a freeway will become so oriented as part of the street system of an area that the portion of the public which now relies on place names should be able to make effective use of it without reference to place names, being guided only by street names and route numbers. Thus, place names should be a supplement to the basic sign message, and not an inherent part of it. The decision to use place names should be a conscious one, coming only after careful analysis of the functions they can perform in the specific situation being considered.

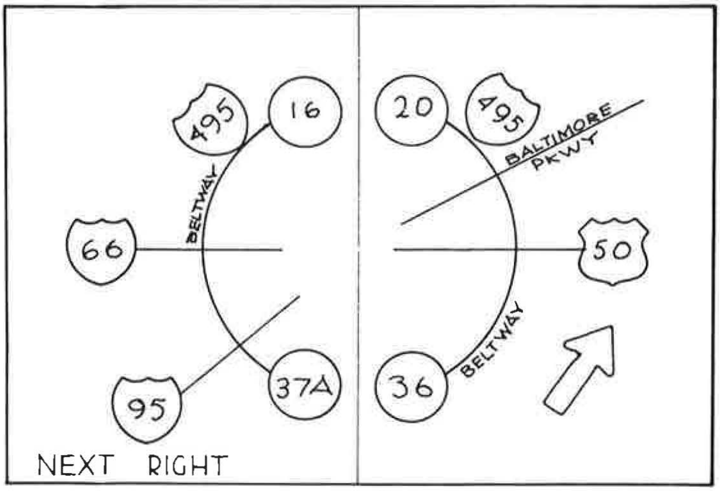
Concept 3—At the interchange of a radial route with a beltway, limit signing destinations to route intersections, regional areas and identifiable physical features on the beltway route, and exclude destination names except as a supplemental guide not normally repeated in the interchange signing sequence.

As the experts indicated, the question of how to direct motorists around a roadway forming a closed loop is probably the most difficult one to answer. None of the information-gathering techniques used provided a definitive answer, but some insight into an approach to the problem was developed.

The personal interviews conducted at BPR indicated that among residents of the Washington metropolitan area there is a fairly widespread awareness of route numbers or names (if not numbered) of the major radial routes. In most cases, these routes are Interstate or US numbered routes. It thus would appear feasible to sign the radial route at its junction with a closed loop (beltway) by using destinations that are in fact beltway junctions with major radial routes intersecting either half of the loop. Route



Advance Guide Sign



Gore Sign

Figure 9. A suggestion for completely symbolized interchange guide signs on the approach to a beltway. The arrow on the advance guide sign points to the interchange being approached and indicates the approach is from inside the loop. The exit numbers at the top of the gore sign indicate the first complete interchanges in each direction from the entrance. Field testing is required to test driver reactions and understanding.

numbers should be readily understandable to the stranger and recognizable to the metropolitan area resident.

The alternative to using major routes as destinations is to use place names as is presently done. The problems created by using place names as primary destinations are many but all relate basically to the fact that places of equal importance are usually not located at well-spaced intervals around the circumference of the beltway, nor are there usually off-route points of equal importance to give directional pull. However, as supplemental information during the interim period discussed under Concept 2, a few selected place names could give guidance to area residents on the shortest distance around the loop to their destination. Again, eventually, the relation of the loop to the area should become known well enough to eliminate place names.

Having decided to use junctions of major routes as the principal means of giving directional information, the next question is "What relationship should the selected junctions have to the point of entrance?" Again, there is no easy answer, but an arbitrary rule has been developed based on the Capital Beltway which may have application at other locations. For motorists approaching the Beltway from outside (inbound toward D. C.), junctions approximately 90 to 150 degrees from the point of entrance would be selected as destinations. In the opposite direction (outbound from D. C.), junctions no more than 90 degrees from the point of entrance would be selected.

When a radial route, with a single route number like the Capital Beltway, is bisected by a linear freeway route with the same route number throughout, the beltway should not be signed as a bypass for this through freeway; rather, in accordance with the guidelines given previously, other junctions should be selected as destinations.

Unlike the Capital Beltway, a radial route interchange involving more than one route number on the beltway is comparatively simple to sign, because directional differentiation is achieved through use of these different route numbers.

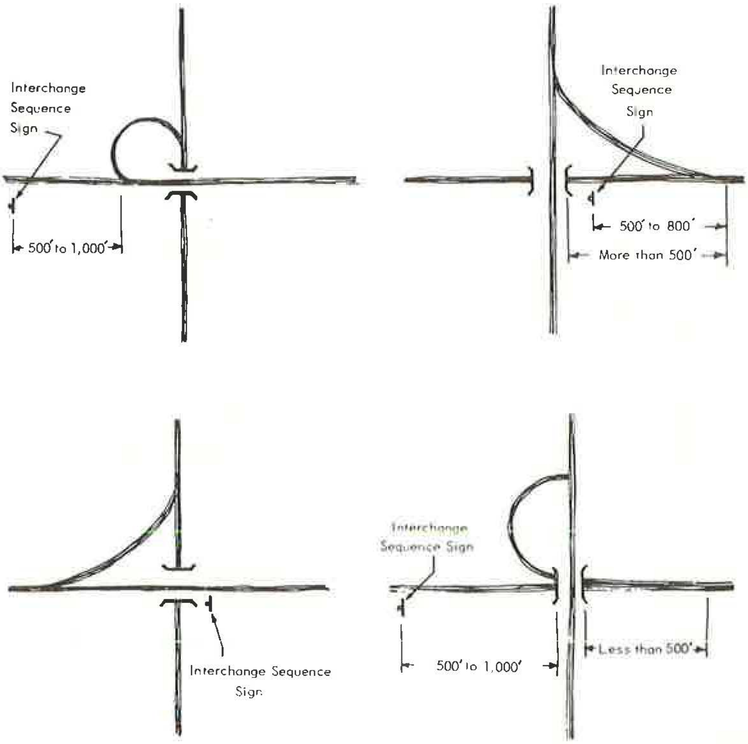
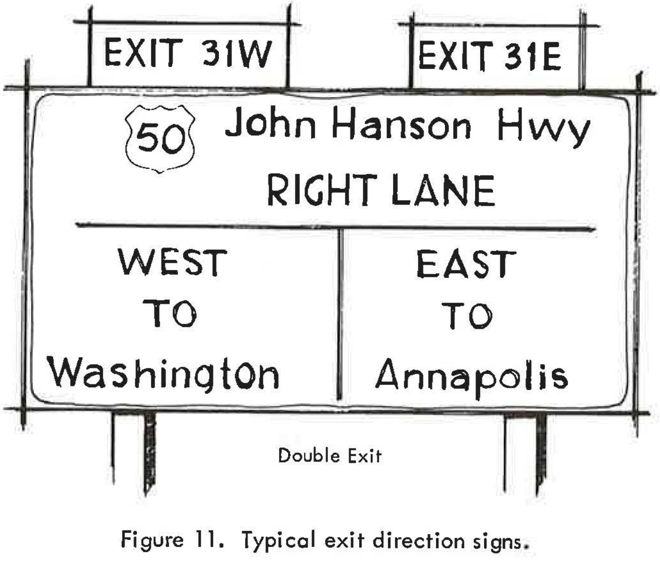


Figure 10. Typical locations of interchange sequence sign based on interchange design.

At one point in the study, an effort was made to incorporate the exit number scheme on the Beltway into radial junction signing. This would give directional information, and answer the question, "Which way is shortest for interchanges approximately 180 degrees from the entrance point?" None of these ideas could be successfully spelled out in words, but symbols appear to be an avenue which merits further exploration. Figure 9 is an example of how a symbol used on an advance sign could be split to show segments of the loop best reached by each of two interchange ramps. The amount of information which could be placed on such signs and assimilated by the driver requires study beyond the scope of the present project. This study then has come to the point where, as a matter of concept, the most practical means to sign the interchange of a radial route with a beltway is to select the junctions of a few principal radials, regional areas, or well-known physical features as destinations, using place names only as secondary, interim information.

Single Exit



Double Exit

Figure 11. Typical exit direction signs.

Selected Signing Criteria

Based on the concepts just described and the information acquired in this study, a number of specific signing criteria can be identified. The most important of these are listed below. Note that many have application to linear freeways as well as beltways.

1. The interchange sequence sign should be a standard element in beltway signing.
2. The location of the sequence sign should be just beyond the last exit ramp of an interchange, as shown in Figure 10.
3. The gore sign should always be mounted overhead and illuminated on a structure 200 to 300 feet in advance of the exit ramp nose.
4. At a two-exit interchange, it is desirable to mount the second gore sign overhead.
5. The exit direction sign would become a standard signing element and always carry the message "Right (or Left) Lane." It would be mounted about 2,000 feet in advance of the gore sign. If there is more than one exit at the interchange, information for each exit would be included on the sign as shown in Figure 11.
6. Articles and prepositions should be added to guide signs to increase their legibility (see Fig. 14).
7. The advance guide sign would be used only at "Major" (as defined by AASHO) interchanges and then only when it can be located no closer than 800 to 1,000 feet in advance of the exit direction sign. When the distance from the gore is less than one mile, an overhead structure should be mandatory.
8. Every gore should be marked with an EXIT or RAMP sign to identify the point of departure of the ramp from the main roadway lanes.

An in-depth analysis such as that undertaken for the larger project on which this paper is based could specify criteria for each of the 11 elements of freeway signing. These 11 elements are as follows:

- Orientation Sign Series
  - Interchange Sequence Sign
  - Through Lane Sign
  - Confirmatory Route Marker
  - Mileage Sign
  - Trailblazers
- Interchange Guide Series
  - Gore Sign
  - Exit Direction Sign
  - Advance Guide Sign
  - Supplemental Guide Sign
  - Exit Sign
  - Destination Sign

ACKNOWLEDGMENTS

This paper is based on a research project conducted for the U.S. Bureau of Public Roads by Alan M. Voorhees and Associates. The report for the project, entitled "Freeway Signing—Concepts and Criteria," is broader but in order to present a paper of manageable proportions, it was decided to limit this presentation to beltway signing. The authors wish to express their appreciation to the U.S. Bureau of Public Roads for permitting this paper to be prepared and presented to the Highway Research Board.

REFERENCES

1. Schoppert, David W., Moskowitz, Karl, Hulbert, Slade, and Burg, Albert. Some Principles of Freeway Directional Signing Based on Motorists' Experiences. HRB Bull. 244, 1960, pp. 30-87.
2. Webb, George M., Dentino, Bruno, and Israel, Rudolph J. Correlation of Geometric Design and Directional Signing. California Division of Highways, revised 1959.

3. Driver Needs in Freeway Signing. Automotive Safety Foundation, Washington, 1958.
4. Interstate Guide Sign Policies. AASHO Operating Committee on Traffic, 1965.
5. Schoppert, David W. Traffic Control and Roadway Elements—Their Relationship to Highway Safety. Automotive Safety Foundation, Washington, 1963.
6. Nisbet, Richard A. Signing Study of a Typical Interstate By-Pass. Montana State Highway Commission, 1964.
7. Manual for Signing and Pavement Marking. AASHO, Washington, 1961.
8. Hulbert, S. F., and Burg, A. The Effects of Underlining on the Readability of Highway Destination Signs. HRB Proc., Vol. 36, 1957, pp. 561-574.
9. Spelman, H. J. Evaluation of Improvements in Traffic Control on the Pentagon Road Network. U.S. Bureau of Public Roads (unpublished report), 1956.
10. Manual on Uniform Traffic Control Devices for Streets and Highways. U.S. Bureau of Public Roads, 1961.

Discussion

T. DARCY SULLIVAN, Assistant Director, Traffic Engineering Division, Traffic Institute, Northwestern University—During the last several years as the Interstate Highway System has begun to take form, there has been a growing recognition of the importance of its signing. The "Interstate Sign Manual" published in 1961 sets forth the basic philosophy and techniques for the signing of the Interstate System. However, I am sure that anyone who has ever attempted to design the signing for a freeway facility in or around an urban area has recognized the limitations of the "Interstate Sign Manual" and the problems encountered in attempting to follow its techniques. The paper which we have just heard has identified many of the problems commonly encountered and done so in a quantitative manner. I am sure that the conclusions reached will not only have an immediate and direct benefit for the motorist driving in and around the Washington, D.C., area but will also be of significant value at such time as the much-needed revision to the urban section of the "Interstate Sign Manual" is undertaken.

It seems to me that many of the difficulties cited and concepts developed in the report have equal application to non-circumferential routes. For instance, the problem of close interchange spacing certainly is not unique to a beltway. The Capital Beltway with 37 interchanges over its 66-mile length has an average spacing of just under 2 miles. The freeway system serving the Chicago metropolitan area includes 124 interchanges on 105 miles of roadway. This average interchange spacing (approximately 0.8 of a mile) is probably not unusual for an urban area where an attempt is made to provide access to most or all of the streets comprising the arterial system. In such a case, interchange spacings of 1 mile or even ½ mile are not unusual and the ultimate may very well be the section of Chicago's Kennedy Expressway adjacent to the Loop where motorists face 7 decision points within 1 mile.

The existence of a multiplicity of communities around an urban center obviously has a distinct impact on the signing of any type of freeway route. Again, drawing from the Chicago metropolitan area with which I am most familiar, there are approximately 123 suburban communities in the metropolitan area.

While not an identical problem, a third similarity between a non-circumferential route and a beltway arises when a primarily east-west road such as I-94 traverses a metropolitan area and travels for some distance in a north-south direction. This in effect creates a route which has no direction which can be signed without causing confusion to the motorist. If it is signed as "I-94 EAST" or "I-94 WEST" the local motorist who knows its true geographical direction is likely to be confused. On the other hand, if it is signed "I-94 NORTH" or "I-94 SOUTH" the long-distance interstate motorist may be misled.

If we can accept that the problems of signing a beltway and almost any other urban freeway route are similar in many ways, then it also follows that many of the concepts developed for signing a beltway would also apply equally to other freeway facilities. Let us then review the signing concepts developed in the report and check their applicability to urban freeway routes in general.

Concept 1—Provide orientation through the consistent application of a series of sign elements which will provide sequential and confirmatory information for the motorist.

The sign elements which might be included in such a series are the interchange sequence sign, the mileage sign showing distances to major points, the route confirmation marker, and the through lane sign used at the gore of some interchanges. As is indicated in the report, on freeways with close interchange spacings, one or more of these signs are often omitted because of lack of spacing between interchanges. While there is no nationally prescribed pattern which should be followed in deciding which sign to omit and which to include, most departments having the responsibility for signing of freeway routes have established local patterns. In the Chicago area, for instance, the mandatory use of the through traffic sign at all interchanges has been discontinued on the assumption that the through lanes will be to the left unless otherwise indicated. The space thus made available can then be used for additional advance warning for other interchanges. In addition to providing the added advance warning desired by so many motorists, the combination of signs located on an overhead sign structure becomes a modified form of the interchange sequence sign.

As a further aid to motorists' orientation the Illinois Division of Highways has installed a series of numbered signs on each light pole along the Stevenson Expressway. The numbers of these signs are tied to the Chicago block numbering system. While the signs were installed to meet the specific problems created by a diagonal route superimposed on a grid arterial system, they also provide a means of continuous orientation for the urban motorist similar to that provided by the mileage markers in a rural area.

The combination of these signs thus fulfills the first concept, which is to provide an orientation guide sign series which is consistently applied to each interchange on a freeway and which creates a common thread running through all interchanges, and further, to identify intermediate points which will help a motorist locate himself along his route.

Concept 2—Establish route numbers and route names as the primary elements of interchange guide signs and reserve the use of place names for selected locations where they give the motorist directional orientation which could not be otherwise provided.

In the signing of the early freeways in the Chicago metropolitan area, one or two suburban municipalities were selected for use in the signing at each interchange. The communities were selected for their orientation value in guiding the motorist at interchanges. Selection was based on the size of the community, its distance from the expressway, and its direction from the expressway. Over the years, this has proved a major source of confusion for many motorists and a constant headache for the responsible authorities. Community pride and constantly changing populations combined to produce a steady stream of requests for change or addition from both municipal officials and the general public.

On the most recently constructed expressways and when major sign modernization is undertaken on any of the older freeways, the use of suburban place names is being dropped completely. The only place names currently being used are those of distant large cities, bordering states, and the large airports serving the metropolitan area. In the areas where this has been done, there has been only moderate and short-lived public reaction, most of it from the residents of communities whose names have been removed from the sign.

A logical corollary of Concept 2 would be the use of freeway proper names at major interchanges. The justification for this is based on the answer to a fundamental question: Will urban freeway users ever develop a familiarity with "Interstate" numbers? Drivers in most urban areas do not refer to "I" routes when talking nor do they seem to orientate to them when driving. I realize that this is contrary to the U.S. Bureau of Public Roads' policy. This poses a second basic question: Which is the easiest to change, policy or the driving public?

Concept 3 pertains to the interchange of a radial route with a beltway and obviously has no general application to urban freeway routes.

In summary, the lack of realistic national standards for freeway signing in urban areas has led to the development of fifty or more sets of local practices. Some of the concepts developed in the present report appear to have general application to urban freeways and may provide a basis for the development of a national policy. Of primary interest in this regard will be Concepts 1 and 2, which point the way toward a standard sign sequence and stronger criteria to be used in the selection of sign legend.

Once an "Urban" supplement to the "Interstate Sign Manual" has been developed and approved, its use in the modernization of existing freeway signing should be encouraged by the U.S. Bureau of Public Roads, through the approval of matching funds for this purpose.

GENE P. D'IPPOLITO, Ohio Department of Highways—Those who develop sign plans for freeway systems, especially closed loop freeways, will welcome this paper for its practical approach to freeway signing problems. This discussion, due to the nature of the paper, has been based primarily on further implications which may be drawn from the conclusions and recommendations.

The question still to be answered is: "How can the freeway guidance needs of all types of motorists be provided?" This is the ultimate goal in freeway guidance which may not have an answer. Therefore, the needs must be determined and then ranked in importance so that the message conveyed is the most important one to the driver having the greatest need. This, in itself, is an admittance that the needs of some will not be provided and that driving errors can be expected. It then can be asked: "What percentage or number of errors can be tolerated? Can these be driving errors resulting in minimum hazard to the driver and surrounding traffic?"

A credit to the paper is that specific elements have been explored resulting in specific recommendations. Too often in the past signing problems and recommended solutions have been in generalities which offered no assistance in most specific applications. Words such as uniformity are quite popular terms but there are no two urban or suburban freeway interchanges that are exactly similar in respect to the signing required. A specific treatment proven successful at one interchange will not be sufficient at another seemingly similar interchange.

The significance of using freeway names is not discussed in the paper. The use of freeway names is generally avoided due to such problems as map identification, insignificance to non-local drivers, sign message space requirements, and de-emphasis of route numbers. Since official route markers, unique in design, have been established for the Interstate System it seems that a driver should not be required to read a name each and every time he is confronted with an Interstate route marker. It is surprising that a recommendation made by the experts was to expand the use of the freeway name to be included as part of a trailblazer symbol. The use of a freeway name to identify it as a closed loop freeway would have no significance unless the terminology was standardized.

A concept of guide sign treatments not often thought of is that any guide sign sequence must tell the driver exactly where he is located. Many other problems are avoided when this information is successfully conveyed to the driver. Much of the paper is devoted to the methods of conveying this information, most of which may well become accepted standards.

Although the Capital Beltway is a completed facility, the freeway system of which it is a part is yet to be completed. Is the existing traffic similar to the type of usage for which the Beltway was designed? Observance of other freeway systems developing during stage construction has shown that usage changes. This also has advantages in that driver familiarity with the freeway system can grow with the growth of the system.

Driver problems and errors are due to numerous contributing factors. Can we accurately determine and isolate those problems caused by signing? What percentage of the traffic can we expect will make errors even under ideal conditions with the best possible sign guidance? Answers to these questions would provide a yardstick to measure comparative quality of sign guidance systems. A freeway, by its design, encourages an attitude of more relaxed driving. Does this attitude act as a handicap to the driver in his response to sign messages? Drivers on a freeway will risk making an unusual manuever to leave at a certain exit because of the difficulty in returning to that point if the exit is not made. Due to this difficulty in returning, an error is made which would not have been detected if it was an "around the block" type of situation due to a missed turn on a lower type facility. Do the pressures on a driver from the character of the traffic stream also result in errors even though the signs may have been proper?

An interesting phase of the study would have been to analyze each trip specified on the questionnaire returns to see how the sign messages applied to the trip. This analysis would also offer data for testing the concept of using route intersections as destinations at radial route interchanges. Concept 3 in the paper recommends the relative location of the route intersections in respect to the radial route interchange. The inference from this criterion is that inbound drivers use a greater length of the Beltway and outbound drivers use a relatively short length. This is a logical assumption and may have been substantiated by a trip analysis. Can it be assumed that a trip involving a short length of the Beltway is planned better and the driver has better knowledge of the routes? The answer would provide an insight into the needs of outbound drivers vs inbound drivers.

It is gratifying to note that a major conclusion in the paper is the recommended deemphasis on the use of place names. There is no doubt that the most perplexing problem of freeway signing is the selection of destination names and the pressures for additional or different names. Modern guide signing started with the route number as the primary guidance system. It is unfortunate that those who established freeway sign standards gave such prominence to the size and location of place names on freeway signs. The cycle is being completed with the proposal to set back place names to their secondary role as they properly should be.

The problems caused by incomplete interchanges are normally attributed to the lack of all movements in the interchange. Normally a freeway system is designed based on origin-and-destination studies to provide the maximum service regardless of where sign routes are located. The sign route system should be studied and revised to best correlate with the freeway system and other routes. Route revisions can help alleviate problems due to incomplete interchanges. Changes in street names should also be considered where clarification of freeway signing can be accomplished by so doing.

A logical question that should be asked after review of the paper is: "Does the use of a single number for a closed loop freeway have any merit?" It is understood that many major factors are involved in the assignment of Interstate route numbers; nevertheless major operational problems in traffic guidance deserve consideration. Different routings and numbering systems should be explored to determine the relative merit of each. Allocating the linear route onto the Beltway with different number assignments to sections within the confines of the Beltway offers several distinct advantages. Specific destinations and cardinal directions can be assigned to all segments of the freeway system. A disadvantage of overlapping numbers and the difficult assignment of numbers to all directional segments of the Beltway would arise. Although routing assignments are often difficult to revise due to many other factors, the pursuit of maximum efficiency in a freeway system should not ignore any possibilities to overcome operational problems.

The present paper makes a significant contribution toward the improvement of guidance concepts on a closed loop freeway and also linear freeways. It also opens avenues for needed additional research work.

SLADE HULBERT, Institute of Transportation and Traffic Engineering, University of California, Los Angeles—Perhaps the most important aspect of this report is the conclusion that two independent research techniques resulted in determining the same highway locations that were causing difficulties for motorists. Locations where the directional signing was found to be in violation of certain basic principles were also those locations where trouble was actually occurring. Thus, perhaps for the first time in this important field of work, evidence is presented confirming the validity of basic principles that were set forth in earlier work.

A second major contribution of this work is the conclusion that beltways as a category of highway facility require a different set of signing principles from straight-through routes. It is important to bear in mind that the suggested changes in signing are merely suggested changes and have not been made; therefore, they could not be evaluated. It is to be hoped that not only will these changes be made, but that some measurements will be taken of the effectiveness of these changes.

The authors present some concepts that seem to be at variance with the goal of uniformity. For example, the authors state that directional signs should contain the most appropriate information for the particular situation. Implicit in this statement is the fact that the most appropriate information may differ from location to location, and would be therefore at variance with the concept of uniformity. It is important here to understand that the appropriate information need not and should not be at variance with the basic principles of freeway signing. The authors' conclusions suggest to me a concept of uniformity of principles rather than a more narrowly defined, rigid concept of uniformity.

The study has clearly described the potential value of field observations. This successful attempt to quantify field observations represents a notable contribution in itself. Traffic engineers have always used such observations in their work, but research use and documented evidence of such observations are, unfortunately, rare.

An important statement is made that the freeway system offers no easy source for the lost driver to obtain information. In this respect, the reports of the use of two-way radios is noteworthy. Fifty confused drivers a month reporting over two-way radios must represent a very large portion of those drivers whose vehicles are equipped with two-way radios and who were driving in the study area at the time.

For the first time, the suggestion of a "normal" proportion of motorists experiencing difficulty, or what could be called a normal confusion level, is set forth and a value suggested of 0.2 percent. The potential merit of using a "confusion index" as a method for rating interchanges or exit designs is presented in this report but may tend to be overlooked. I hope it is not. It was interesting to note that a higher percentage of drivers reported having problems leaving the system than in entering it, which is exactly opposite of the trend discovered in the study performed in Los Angeles.

It is important to note that, in one of the surveys, strangers were not interviewed and that the researchers acknowledged the important potential differences in response. It is to be hoped that future research will also make this distinction.

An important discussion is presented of "decision rate." Decisions every 60 seconds, and in some cases every 45 seconds, are suggested for urban freeways, and these high rates are contrasted with much lower rates for rural freeways. The implications for traffic safety are obvious for both extremely high decision rates and extremely low rates. Designers of interchanges also utilize this concept to some degree, but there is need for joint consideration of the total decision rate as influenced by other factors inside and outside the vehicle. Such a total rate, if available, could be a major highway design parameter. But the point made by this study is that it is not the driver's decision rate per se, but that rate relative to his degree of orientation or his "feeling of confidence about where he is relative to where he is going" that is important, not only for his well-being but for the safety and efficiency of the highway facility. I don't think this point can be overstressed or that anyone can fail to agree with it. However, the average driver seems only to be aware of the end result of inadequate orientation, and his statements characteristically are, "there is not enough warning," "speeds are too high," or "I got lost." Herein lies a message from this report extremely relevant to the engineering profession; namely, the user does not know the true reason for his discomfort and therefore brings political and other pressure to bear for "more signing" or "more advance notice." If his clamor is acceded to, the situation may actually be worsened.

At least one example of "negative reasoning" is included in this paper. This human factor is perhaps the most subtle problem faced by the signing designer. The omission of information can, in certain contexts, be extremely misleading and must be taken into account insofar as possible. Perhaps exposure of proposed signing to drivers completely naive about freeway design and the locale is the only way to cope with this problem. Once a person knows the "lay of the land" he cannot react as though he does not; nor can he imagine all the ways in which a naive person will react.

It is encouraging that this study not only identifies and quantifies certain aspects of signing design that need improvements, but also provides some clearly stated suggestions for making improvements. From this starting point, additional research or trial installations can be implemented.

STEPHEN G. PETERSEN and DAVID W. SCHOPPERT, Closure—It is gratifying to have three discussers support the findings of a research study to the extent that Messrs. Sullivan, Hulbert and D'Ippolito have in this instance. A few additional remarks are nevertheless warranted.

Sullivan makes the point that the findings of the study can be extended beyond beltways to linear freeway routes with little or no modification. The authors are pleased to hear this for they made similar recommendations to the U.S. Bureau of Public Roads in the larger report on which this paper was based. The facilities Mr. Sullivan mentions would be excellent candidates to test some of the concepts set forth in the paper.

Hulbert has emphasized some of the major points in the paper and stated them even more succinctly than the authors. His restatement of the inability of drivers to tell the engineer exactly what is wrong with signing is particularly good. The engineer, after hearing numerous ill-defined complaints, shrugs his shoulders and mumbles something about "poor driver training." In fact, the problem may be quite subtle and need concentrated study not only by the engineer but by human factors oriented specialists as well. We must take more pains to see behind the driver's often quoted but unsophisticated complaints to determine his real problems.

Because his everyday duties involve freeway signing, the authors are particularly pleased with the support of the conclusions and recommendations provided by D'Ippolito. The general questions he raises are logical extensions of the work started in California in 1958 and pushed forward in this study. They illustrate that there is much more to be done.

In response to D'Ippolito's more specific questions about the Capital Beltway, it appears that as future facilities are completed it might carry less "stranger" traffic as a percentage of the total traffic than it does now, since the Beltway presently serves as the terminus of linear routes which will eventually go through the District of Columbia.

Another question dealt with the analysis of outbound vs inbound trips. Not enough trips to and from points some distance removed from the Beltway were obtained to validate the decision to choose points behond the 90-degree points for inbound trips and less than 90 degrees for outbound trips. These selections were instead based on a logical deduction that a driver starting at the center would be most likely to take a radial oriented somewhat in the direction of his eventual destination, whereas one inbound may be seeking points farther around the loop.

The authors firmly believe that many of the findings in this study, if applied to present-day freeway signing, would add significantly to the driver's ability to navigate these high-speed roads. It is hoped that there will soon be opportunities to prove this through a program of controlled installations sponsored by the U.S. Bureau of Public Roads.

Effect of Rumble Strips at Rural Stop Locations on Traffic Operation

ROBERT D. OWENS, Minnesota Department of Highways

•DURING the last few years the nation's motor vehicle accident rate has been gradually increasing. The National Safety Council indicates that 1964 motor vehicle fatalities were 47,800, approximately 4,300 more than in 1963 (13). Accident data reveal that many highway accidents occur at rural intersections with stop sign control. Analysis of accident records shows that most of them were caused by violation of the stop controls. Normal corrective measures, such as signals or grade separations, are often too costly. Signals especially are not usually warranted because of the low traffic volumes (7).

Since stop sign controls and all other associated warning signing normally installed at a rural highway intersection are apparently not fully effective, it has become necessary to develop devices which will encourage the motorist to stop. One such device that has been used with increasing frequency in recent years utilizes audible, tactile, and visual stimuli from coarse-textured pavement surfaces alternating with the smooth texture of the road. The most common name for these roughened pavement surfaces is rumble strips.

This study is a comprehensive investigation of the influence that rumble strips produce on traffic operation at rural stop locations.

PREVIOUS STUDIES AND BACKGROUND

The idea of an irregular surface at stop sign approaches was apparently introduced by the Cook County, Illinois, Highway Department in 1954 (2). Cook County installed a non-intermittent rumble area for a distance of 300 feet from the intersection. Well over 200 stop sign intersections in Cook County have been treated in this way. Stop sign observance studies at one such intersection showed the percentage of drivers making a full stop increased from 46 to 76 percent after the rumble areas were installed. Observations were made of more than 1,000 vehicles in this study.

In a 1962 report, Kermit and Hein (5) concluded that accident rates, speed, and deceleration rates were greatly reduced after the installation of transverse strips, defined as "...a series of 25-ft long areas of rough textured aggregate placed on the appropriate lanes at 50- to 100-ft intervals." The study was of three installations in Contra Costa County, California. The speed distributions for the "before" and "after" conditions were presented without any supporting statistical analysis. One of the installations, on which many of the results were based, involved the approach to a curve.

A recent article in a national highway engineering periodical indicates that some state highway departments have recently made experimental rumble strip installations (1). The majority of the installations are based on the Kermit and Hein study with respect to spacing and application. A few, however, have employed some minor variations. As reported in the article, a one-year before-and-after accident study at ten intersections by the Illinois Division of Highways indicates a 27 percent reduction in total accidents after the intersections had been treated with rumble strips. Illinois also reports that "Accidents caused by running stop signs have been virtually eliminated." A preliminary one-year accident study by the Delaware State Highway Department at three locations indicates a 50 percent reduction in accidents.

Paper sponsored by Committee on Traffic Control Devices and presented at the 46th Annual Meeting.

A few theses somewhat related to this study have been written regarding transverse pavement markings as a driver stimulus on stop sign approaches. One, by Puy-Huarte at Ohio State University, was used considerably as background material for this study (12). Puy-Huarte's study was conducted at two stop sign intersections and at one hazardous curve in Ohio. The only field observations consisted of "before" and "after" speed measurements of individual approaching vehicles at various points. Puy-Huarte found that the transverse pavement markings caused a change in vehicular deceleration patterns. His results, however, showed no consistent change in vehicular speeds. This was probably caused by the fact that different spacings were used for the transverse pavement markings at the different locations.

Although, as previously indicated, several rumble strip installations have been installed at various individual problem locations, a comprehensive study has never been conducted regarding their effect on traffic operation exclusively at rural stop locations. These appear to be the most logical places for this type of traffic control device.

This study was carried out at the request of the Minnesota Department of Highways. The interest of the Department was to develop some device that would additionally alert drivers to the necessity of deceleration at rural stop locations and thereby cause safer operation at these locations. The Minnesota Department of Highways provided all of the funds, manpower, and equipment for this study.

OBJECTIVES AND METHODS OF STUDY

Four broad principal objectives established for this work were (a) to study the combination of audible, tactile, and visual stimuli upon traffic operations; (b) to measure the effect of rumble strips on the mean or "average" speeds of traffic approaching a rural stop location; (c) to make a complete study of stop sign observance and vehicle placement before and after installation of rumble strips on the approach to an intersection; and (d) where sufficient information is available, to determine any trends in accidents at locations where rumble strips have been installed.

Methods

In order to study the effect of rumble strips on traffic operation, it is necessary to gain a knowledge of traffic operation under "before" conditions when no such strips exist. Only in this way will it be possible to know if rumble strips, once they have been installed, exert any influence on traffic operation.

The first studies in this investigation were therefore focused on traffic operation and behavior in approaching the intersections. Speeds were studied at several points along the approaching paths. It was then possible to determine the relationship in average speed and speed distribution at these points before the rumble strips were installed.

Another measure which was considered of importance was the observance of the stop sign controls by traffic. In other words, how much of the traffic does not come to a complete stop as required by law? How much of the traffic does not stop at all? To answer these questions, stop sign observance studies were conducted.

Because it was feared that rumble strips might cause traffic to cross the approach centerline to avoid driving over the roughened pavement sections, centerline observance studies were also conducted. The normal pattern of traffic behavior as to centerline observance was thereby determined.

As soon as sufficient data on traffic operation and behavior had been obtained, the proposed rumble strips were installed at the intersections. Similar speed, stop sign observance, and centerline observance studies were then made and the data evaluated as before.

The results were compared with the results of the "before" condition. In addition, accident records were examined at each intersection for a period of years prior to the installation of the rumble strips. Any reported accidents since installation have been analyzed to determine any apparent trends. It should be realized, however, that sufficient time has not elapsed since the rumble strip installations to draw any definite conclusions regarding accident severity and frequency.

SUMMARY OF RESULTS

It was found in this investigation that rumble strips significantly reduce the average speed of traffic approaching rural stop locations. The reduction in average speed is approximately equal at each observed distance along the approaching paths. The degree of dispersion, however, is slightly increased after the installation of rumble strips. Rumble strips apparently do not affect all motorists uniformly.

The number of stop sign violations was materially reduced as a result of the installation of rumble strips.

No significant difference was found in the amount of centerline violations by traffic approaching the intersections after the installation of rumble strips.

A decreasing trend in the number of accidents was found at two locations, presumably as a result of the rumble strip installations. Unfortunately, not enough "after" time has elapsed at the other installations to determine any trends. No significant conclusions can be drawn concerning accidents at any of the intersections, however, because of the erratic accident patterns at the intersections during the past five years.

THEORETICAL BASIS AND FIELD APPLICATIONS

It is generally accepted that four general distracting phenomena may cause a driver to divert his attention from the primary task of driving and thereby cause him to make serious mistakes (5). They are as follows:

1. There are other distractions competing for his attention, such as advertising signs.
2. He may become bored, fatigued, or drowsy from driving on long, monotonous stretches of road.
3. After driving a long distance at high speed, he may become "velocitated" and will not slow down until actual congestion impedes progress.
4. His previous experience may lead him to ignore information or warnings because he feels capable of judging the situation himself, such as disregarding stop signs at low volume intersections with good sight distances.

It is well known that reaction is the response of inner conscience to external sensorial stimuli. The stronger the stimulus, the stronger the reaction. The duration and degree of attention is also dependent on the intensity of the stimulus and the contrast between it and the surrounding stimuli.

The entire principle of rumble strips is therefore to provide an additional strong stimulus to increase driver reaction and attention. The four distracting phenomena mentioned are undoubtedly responsible, either singly or collectively, for most of the accidents at rural stop locations. Rumble strips are intended to utilize the driver's visual, auditory, and tactile senses simultaneously to obtain the desired reaction and warn him of the approaching intersection.

The use of an audible stimulus, particularly, is intended to provide faster reactions than is normally associated with visual stimuli alone. Matson, Smith, and Hurd (8) refer to research which showed brake reaction times were faster when an audible signal was used than when a visual signal was used for a variety of different conditions of vehicle movement and foot position. Thus, the increased level of noise caused by the rumble strips is intended to have a beneficial effect on traffic operation.

Study Locations

The preceding discussion has shown why rumble strips should be effective in improving traffic control where normal practice has not been entirely satisfactory. On this basis, rural trunk highway junctions in southeastern Minnesota were chosen for rumble strip installations. The typical rural trunk highway intersection in this area is characterized by relatively low traffic volumes, very high average operating speeds, and open sight distances. Accident rates at these locations are normally low. The accidents that do occur, however, are usually very serious in nature, undoubtedly due to the high average operating speeds. For this reason it was decided to install rumble strips at a few rural stop locations on a trial basis.

The first rumble strip installation was made in the fall of 1962 at the junction of State TH 30 and State TH 56. This is a four-way, at-grade intersection. Trunk Highway 30, having the lowest traffic volumes, is controlled by stop signs from both directions. Trunk Highway 30 is an east-west two-lane highway, and TH 56 is a north-south two-lane highway. Both roads are bituminous surfaced and approximately 24 ft wide.

In the summer of 1963 the second rumble strip installation was made at the south junction of US 16 and State TH 43. This is a "T" intersection where US 16 forms the trunk portion of the T and is controlled by a stop sign. Both US 16 and State TH 43 are two-lane bituminous-surfaced highways approximately 24 ft wide.

Four additional rumble strip installations at rural stop approaches were made in 1964. All of these 1964 installations are at T-type intersections and in each case the approach forming the trunk of the T is controlled with stop signs. All "stopped" approaches are two-lane, bituminous-surfaced highways approximately 24 ft wide. These locations are at the junction of US 63 and State TH 56; the north junction of US 63 and State TH 30; the south junction of State TH 56 and State TH 19; and the north junction of State TH 56 and State TH 19.

Thus a total of six rural trunk highway intersections are included in this study. Five are T intersections and one is a four-way, at-grade intersection. The six intersections include a total of seven stop approaches which have been treated with rumble strip applications. All stop approaches are single-lane approach rural-type highways. Each intersection has at least 1,000 ft of unobstructed sight distance from all approaches. For a number of years each location has been signed and marked in accordance with the current "Manual on Uniform Traffic Control Devices for Streets and Highways" (7). "Stop Ahead" pavement marking warning messages have also been installed at each location since 1960. The average volumes on the stop approaches range from approximately 400 to 1,000 vehicles per day.

Table 1 lists each approach together with the trunk highway location, approach direction, rumble strip installation date, and average daily traffic on the approach. The letter designating each approach is used throughout the text that follows for reference to each location. The subscripts refer to the two approaches of State TH 30 on which rumble strips have been installed at its junction with State TH 56. This provides a convenient means of identifying each approach in the study with its trunk highway intersection and approach direction.

TABLE 1

RUMBLE STRIP STUDY LOCATIONS

Approach	Location	Approach Direction	Installation Date	Approach A.D.T.
A_1	Jct. TH 30 & TH 56	TH 30 Eastbound	10-8-62	640
A_2	Jct. TH 30 & TH 56	TH 30 Westbound	10-8-62	960
B	Jct. US 63 & TH 56	TH 56 Eastbound	7-10-64	395
C	S. Jct. US 16 & TH 43	US 16 Westbound	9-30-63	715
D	N. Jct. US 63 & TH 30	TH 30 Eastbound	6-19-64	745
E	S. Jct. TH 56 & TH 19	TH 19 Eastbound	7-13-64	555
F	N. Jct. TH 56 & TH 19	TH 19 Westbound	7-13-64	590

Each location, together with its letter designation, is shown in Figure 1, which also shows the study locations in relationship to the surrounding area.

Design and Installation of Rumble Strips

Kermit and Hein (5) indicated that they had conducted considerable research regarding the length and spacing of the rumble areas. Utilizing this previous research, all rumble strip approaches in this study were installed with exactly identical designs. This is advantageous in that no additional variables have been introduced in the analysis due to different lengths and spacings of the rumble areas for any of the locations. It would be impossible to compare overall effects between study locations if different designs had been used.

The experience gained since the initial installations indicates that additional experimentation as to length and spacing of the rumble strips is required. Many traffic and highway engineers feel that an optimum design can be developed for maximum effect on traffic operation. Using transverse painted lines on a stop sign approach, Puy-Huarte found that excellent results were obtained with either a geometric or arithmetic progression spacing (12, p. 84). Undoubtedly, these same patterns should be tried with rumble strips.

The spacing of the rumble strips in this study consisted of four strips 25 ft long spaced 100 ft apart; six strips 25 ft long spaced 50 ft apart; and one at the intersection 50 ft long which also acts as a nonskid treatment. The total length of the rumble area is 1,000 ft. A layout of the rumble strip installation at Approach B is shown in Figure 2. It may be considered a typical layout, since all of the other study approaches are constructed to precisely the same pattern.

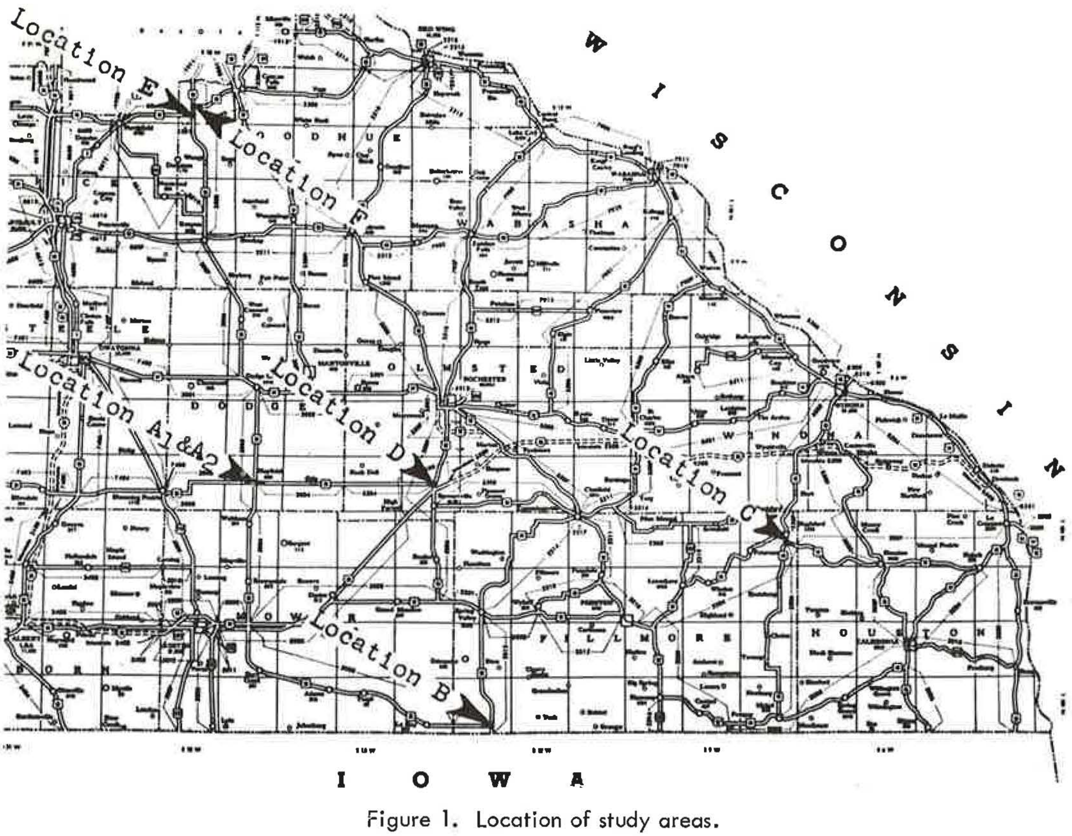


Figure 1. Location of study areas.

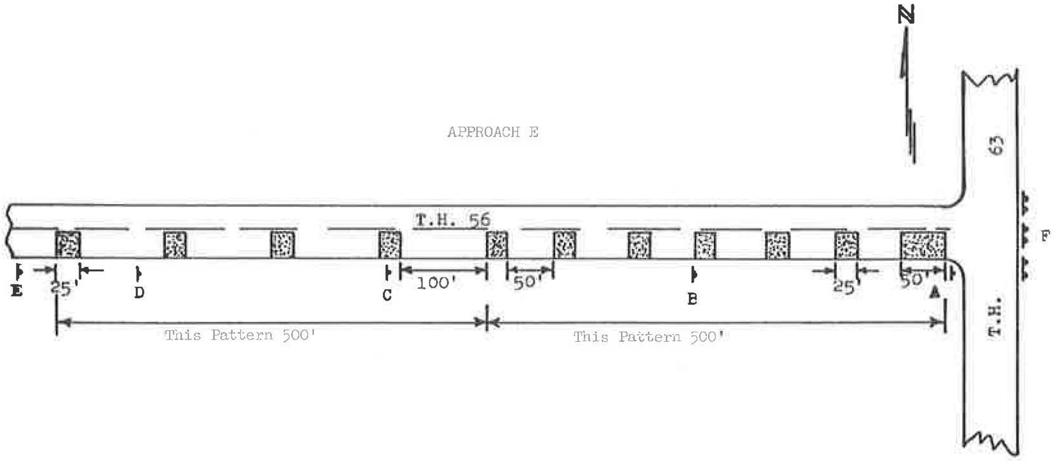


Figure 2. Typical rumble strip installation (Key to signs: A—Stop; B—Destination; C—Directional; D—Junction plate; E—Stop ahead; F—Barricades).

The rumble strips at Approach A_1 are shown in Figures 3 and 4. Figure 5 shows the first strip of the installation at Approach C, located near Rushford, Minnesota. The standard "Stop Ahead" pavement message is easily identifiable. Figure 6 shows Approach C, looking west toward the stop sign. By close inspection, the stop sign may be barely identified.

Briefly, the rumble strips are constructed with ¾-in. maximum size washed aggregates. The aggregate must be very hard so that it will not break down or decompose from traffic wear. The aggregate is bonded to the pavement with RS-3K cationic asphalt emulsion applied at the rate of approximately 0.35 gal per sq yd. Reasonable aggregate retention has been obtained in this way. The audible stimulus seems very satisfactory with the ¾-in. size aggregate.

Similar to the previously mentioned problems of rumble strip spacing, much has yet to be learned in rumble strip construction. The strips require considerable

Figure 3. Approach A_1, near Hayfield, Minnesota, looking east.

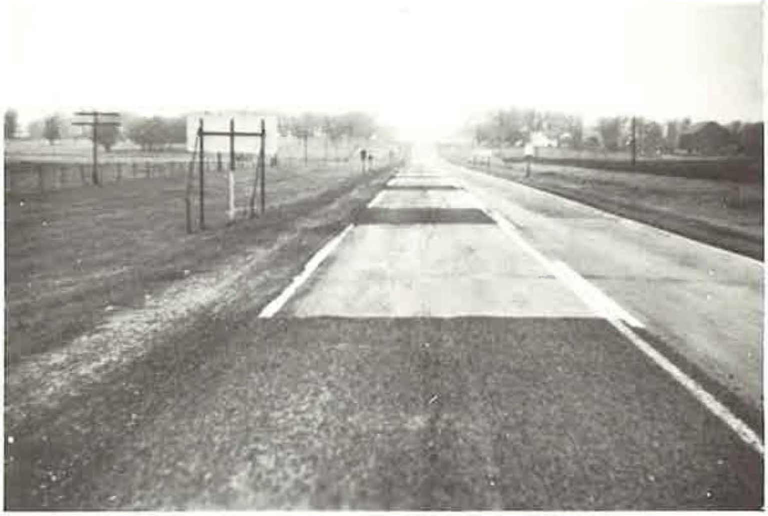


Figure 4. Approach A_1, looking west.

Figure 5. Approach C, near Rushford, Minnesota, looking east.

Figure 6. Approach C, looking west.

maintenance and periodic patching. Chemicals must be used on them during the winter to keep them free of ice and snow because snowplow blades will severely damage them. The original installations on Approaches A_1 and A_2 required replacement in October 1963. The early replacement on these approaches, however, was caused by insufficient asphaltic bonding material in the initial installation. The fairly recent introduction of epoxy resins for bonding agents holds great promise for rumble strip construction. Epoxy resins should help bring the amount of maintenance required down to more reasonable levels.

A close-up of a rumble strip (Fig. 7) shows the contrast in size of the rumble aggregate with an ordinary 6-foot flexible rule. Figures 8 and 9 show how the rumble strips were installed by maintenance forces. Figure 8 shows the placing of paper

Figure 7. Approach A_1, close-up of the aggregate (New Ulm quartzite) used.

Figure 8. Approach A_1, placing paper prior to the application of RS-3K.

Figure 9. Approach A_1, spreading aggregate.

prior to the application of the asphaltic material to provide a neat line of demarcation between rough and smooth pavement. Figure 9 shows the spreading of aggregate on the asphaltic material.

FIELD STUDIES

In the preceding section, the theoretical basis and field applications of rumble strips were developed. This section describes the field studies which were conducted to determine the influence of the strips on approach average speeds and traffic behavior. To this end it was necessary to know the spot speeds of vehicles at different points on the approaches to the study sections and to record the stop sign and centerline observance of approaching traffic.

Speed Studies

The speed observations were made only on free-flowing vehicles. Free-flowing was defined to mean a vehicle approaching the study area without a vehicle preceding within 10 sec or following within 10 sec. These standards are somewhat arbitrarily set, but in view of Greenshields' findings that on rural roads little interference is found at gaps of 9 sec, there should be no interference at a gap of 10 sec (11). Because of the low traffic volumes, relatively few approaching vehicles had a gap of less than 10 sec.

The spot speed observations were made with an Electro-Matic Model S5 radar speed meter manufactured by the Automatic Signal Division, Laboratory for Electronics, Inc., Norwalk, Connecticut. This is a transistorized speed recording device resembling a spotlight when properly mounted on a vehicle. It is a precision instrument for measuring the instantaneous speeds of moving vehicles. It consists of three major separable units: (a) the RF Head Assembly (spotlight); (b) the Amplifier and Power Supply Assembly; and (c) the Indicator Assembly. When set up for operation, these units are interconnected by cables. The speed meter operates within a range from 0 to 100 mph with a rated accuracy of ±1 mph.

Before each series of spot speed checks the radar speed meter was calibrated both by a tuning fork and by measuring the speed of a vehicle having an accurately calibrated speedometer moving in the zone of the speed meter. With this degree of calibration, it is felt that the spot speeds were probably observed at considerably closer tolerance limits than as rated by the manufacturer of the speed checking equipment.

Extreme care was taken during all speed observations to insure that accurate results were obtained. An unmarked vehicle was always used for the speed checks and wherever possible, the vehicle was hidden from the view of approaching traffic. When the speed survey vehicle could not be hidden from view, it was parked inconspicuously in a field entrance or well off the road shoulder. Physical ties were made of both vehicle position and the RF head assembly aiming during the "before" phase at each location so it could be duplicated during the "after" study. Wooden hubs were driven into the shoulder for reference so that the speed was recorded at the exact designated spot for each vehicle.

All field studies were made in essentially the same weather conditions, i.e., clear, dry, etc. Realizing that day of the week and hour of the day is also extremely important, an attempt was made to duplicate these variables for the "before" and "after" conditions. Due to weather conditions, however, the "after" speed study at Approach D was changed from a Thursday and Friday to a Monday and Tuesday survey. Since the change involved only weekdays, this was not considered serious for rural conditions. Except as noted for Approach D, all "before" and "after" spot speed checks were made during the same hours and on the same days of the week. For economic reasons, each spot speed check had to be limited to 2 hours duration. The number of passenger vehicles observed at each check ranged from 30 to 101 cars. The vehicles were classified as (a) passenger vehicles or (b) trucks and buses. The number of trucks and buses observed, however, was much too small to analyze in this study.

The spot speeds were obtained at 300, 500, 1,000, and 1,500 ft from each study intersection. In addition, "before" and "after" spot speed checks were made at each location in an open area on the approach roadway where approaching traffic could not observe either the junction or advance warning signing. Any changes in the speed characteristics could, therefore, be discovered.

Stop Sign and Centerline Observance

In order to properly analyze traffic behavior, stop sign and centerline observance was studied at each location. There were four categories of driver action noted: (a) no stop; (b) rolling stop; (c) complete stop; and (d) crossed centerline. At least 2 hours' data were collected at each approach both before and after the installation of the rumble strips. As in the speed studies, only free-flowing vehicles, having at least a 10-sec gap after the preceding vehicle had cleared the stop sign, were recorded. In addition, observations were not recorded if there was conflicting intersectional traffic within 1,000 ft of the approaching vehicle. This was done in order to record the normal stop and centerline behavior of free-flowing unopposed vehicles. Since the same vehicles were involved, the sample sizes for these observations are approximately the same as the spot speed checks.

The Minnesota Motor Vehicle and Traffic Laws state, "Every driver of a vehicle shall stop at a stop sign or at a clearly marked stop line before entering an intersection, except when directed to proceed by a police officer or traffic control signal" (9). All traffic that complied with this provision of the law was recorded as a "full stop." "Rolling stops" and "no stops," therefore, were recorded for traffic that did not come to a complete stop. "No stop" was recorded only for flagrant violation of the stop regulation and consisted of very few vehicles. If any portion of an approaching vehicle crossed the centerline during the stopping maneuver, it was so recorded.

All field studies were conducted during weekdays under daytime conditions. Table 2 gives the dates of the "before" and "after" studies.

RESULTS OF DATA ANALYSIS

Speed Data

The speed data collected were used to compile the spot speeds of passenger cars at each of the points for every location. Using the spot speed data, the average speed, variance, and standard deviation were computed for each of the points for both the "before" and "after" conditions (Table 3). All of the statistical analysis concerning speed data in this study is based on these values. The number of passenger cars, mean speed, and variance for each approach are given for both before and after the rumble strip installations. Average speed and mean speed are synonymous and are used interchangeably.

It can be seen from Table 3 that a noticeable general decrease in the average speeds occurred after the rumble strip installations at points 300, 500, 1,000, and 1,500 ft away from the intersection in nearly every case. The reason for a decrease in average speeds at a point 1,500 ft away from the intersection was not initially understood until an examination of the approach road profiles showed that the rumble strips could easily be seen on all approaches except at Approach D. Significantly, Approach D shows no change in average speed between the "before" and "after" conditions.

As mentioned earlier, a basic assumption was made that the approaching traffic would have the same characteristics both with and without the rumble strips. Accordingly, the average speeds shown as "Away From Area" in Table 3 are based on the spot speed data recorded at a point where approaching traffic could not observe either the junction or advance warning signing. This allowed the measuring of these characteristics and provided an immediate check on any differences. Table 3 shows that there appear to be only insignificant differences in the average speeds measured at points away from the approach areas.

TABLE 2

FIELD STUDY PROGRAM

Approach	"Before" Data	"After" Data
A_1	10-3 & 10-4-62 (Wed & Thur)	7-1 & 7-2-64 (Wed & Thur)
A_2	10-3 & 10-4-62 (Wed & Thur)	7-1 & 7-2-64 (Wed & Thur)
B	6-2-64 (Tues)	8-11-64 (Tues)
C	9-5 & 9-6-63 (Thur & Fri)	8-6 & 8-7-64 (Thur & Fri)
D	5-29 & 6-4-64 (Thur & Fri)	7-27 & 7-28-64 (Mon & Tues)
E	6-3-64 (Wed)	7-29-64 (Wed)
F	6-2-64 (Tues)	8-4-64 (Tues)

The underlying theory in taking spot speed checks on the approach roadways away from the area is to prove, if possible, that both the "before" and "after" samples are from the same population. If there is no significant difference between "before" and "after" control speeds, any change in the average speeds in the area of the rumble strips can be attributed to the rumble strips.

Examination of the variance in Table 3 shows that in many cases the variance has increased slightly after the rumble strip installations. The variance, however,

TABLE 3

SUMMARY OF SPEED DATA

Distance	Value	Approach													
		A_1		A_2		B		C		D		E		F	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
300	N	67	51	90	73	30	31	53	54	61	57	45	41	48	48
	$\bar{X}$	30.3	26.9	29.7	28.7	32.2	27.3	34.4	28.5	29.7	25.5	28.8	26.8	33.7	31.9
	S^2	21.81	22.00	23.79	22.44	21.31	21.01	43.74	17.51	21.36	34.64	18.27	18.95	19.16	27.49
500	N	52	54	94	71	44	44	53	53	50	42	42	42	50	50
	$\bar{X}$	35.8	32.8	35.2	32.5	38.3	35.0	37.0	33.8	39.5	36.2	37.3	36.1	34.5	30.2
	S^2	24.40	30.2	28.49	30.95	37.75	46.74	35.23	32.49	29.07	45.88	28.84	33.03	29.93	44.14
1000	N	73	63	101	79	35	35	52	52	51	52	39	41	44	45
	$\bar{X}$	45.3	41.9	37.1	36.4	48.5	44.5	48.9	41.8	45.1	45.0	44.8	42.7	43.6	41.2
	S^2	48.68	48.52	38.53	44.70	31.19	43.79	47.91	40.44	45.53	47.72	59.02	51.98	62.20	67.68
1500	N	67	76	100	91	47	47	51	52	39	38	60	63	52	53
	$\bar{X}$	52.7	46.0	39.6	37.5	50.3	47.0	51.7	49.5	47.6	47.6	45.4	43.5	49.8	46.0
	S^2	49.86	56.75	42.74	55.83	58.30	69.04	34.62	51.39	47.56	69.45	68.73	51.83	53.24	51.46
Away From Area	N	72	74	63	67	51	52	57	56	61	64	49	53	55	61
	$\bar{X}$	55.4	55.6	43.7	44.1	57.7	58.1	54.5	55.5	53.1	52.9	46.6	46.6	55.3	55.7
	S^2	48.96	51.25	45.25	43.95	59.31	60.20	52.20	51.59	53.32	55.92	52.36	53.72	51.66	53.70

N = No. of passenger vehicles
$\bar{X}$ = Mean speed
S^2 = Variance

seems to be somewhat homogeneous across the rows between intersections for each distance except in a few instances.

Analysis of Variance of Speeds

To find out whether the average speed of traffic with and without rumble strips was statistically different, and also to find if the average speed data recorded away from the approach area were statistically the same, the significance of the difference of the means between the "before" and "after" samples was tested. The method employed is called analysis of variance. This method is appropriate in this study because it tests the overall or average difference in mean speeds for the seven approaches simultaneously at each distance from the intersection. If the differences among the seven means were tested separately, there would be seven tests to perform for each point of reference. It is not good statistical practice to do this. It would materially increase the level of significance and result in a large loss of precision in estimating the true variance if the measurements of only the two samples being compared are used (3).

Analysis of variance is based on the fact that if the means of subgroups are greatly different, the variance of the combined groups is much larger than the variance of the separate groups. The procedure was conducted at each point for the mean speed and variance data in Table 3. The results, together with the 95 percent confidence limits, are shown in Table 4. The level of significance used throughout the procedure was 5 percent. Table 4 shows that the observed differences in the means is significant at the 5 percent level. It also indicates that the results of the spot speed studies conducted away from the approach areas are not significant at this level. The basic assumption that both the "before" and "after" studies are from the same population is apparently true.

In summary, we may say that in this study the use of rumble strips has caused an overall decrease in the mean approach speeds of approximately 2.75 ±0.85 mph at the 5 percent level of significance.

Index of Dispersion

Once the average speeds have been studied, the question arises as to how uniformly the vehicles stop. The analysis of variance technique has shown that the mean speeds of approaching passenger cars are significantly reduced with rumble strips. The results, however, do not indicate how much the variance has changed, if any, as a result of the rumble strips. At each point of reference this is given by the relevant variance. It is reasonable to calculate an Index of Dispersion between the "before" and "after" conditions as follows:

$$\text{I.D.} = \frac{S_a}{S_b}$$

TABLE 4

RESULTS OF ANALYSIS OF VARIANCE
(Mean Speeds—All Approaches Combined)

Distance	Average Speed (mph)			95% Conf. Limits
	Before	After	Diff.	
300	31.01	27.99	3.02	±0.70 mph
500	36.57	33.59	2.98	±0.83 mph
1000	43.70	41.39	2.31	±0.98 mph
1500	47.26	44.47	2.79	±0.99 mph
Away from area	52.09	52.58	0.49	Not Significant

TABLE 5

INDEX OF DISPERSION

Distance	Pooled Variance (Before), S_b	Pooled Variance (After), S_a	Index of Dispersion, $\frac{S_a}{S_b}$
300	24.76	23.75	0.971
500	30.22	36.86	1.220
1000	46.54	48.71	1.047
1500	50.15	56.99	1.136

Where

I. D. = Index of dispersion
S_a = Pooled variance (after)
S_b = Pooled variance (before)

The pooled variance of any point is given by

$$S_p^2 = \frac{(N_1 - 1)S_1^2 + (N_2 - 1)S_2^2 + \ldots + (N_k - 1)S_k^2}{N_1 + N_2 + N_3 + N_k - k}$$

Where

S_p^2 = Pooled variance
N_1, N_2, etc. = Number of observations in each sample at the various points
S_1^2, S_2^2, etc. = Calculated estimate of the variance for each sample
k = Number of categories or samples being considered.

The value of I. D. represents the ratio between the "after" and "before" conditions. An Index of Dispersion of less than one means that a greater degree of uniformity has been obtained. The values obtained from this ratio are given in Table 5.

It is clear from Table 5 that less uniformity in the speed patterns has been caused by the rumble strips except at a point 300 ft away from the intersections. Evidently the rumble strips do not affect all of the traffic in the same way. Although the mean speeds have been reduced, the speeds are generally more dispersed. The observed increase in variance is probably caused by some passenger vehicles slowing down considerably more than others due to the rumble strips. Unfortunately, speed patterns of individual cars were not observed in this study, and therefore the cause could not be verified.

Speed Frequency Distributions

In order to graphically depict the changes in speeds of passenger vehicles caused by rumble strips, frequency distributions have been prepared for the reference points located 1,500, 1,000, 500, and 300 ft distant from the intersections. The speed frequency distributions represent the total observed passenger vehicles at each of the points. They were prepared by averaging groups of the observed frequencies to secure relatively smooth lines. Figures 10, 11, 12, and 13 show both the "before" and "after" frequency distributions superimposed upon each other for the reference points.

It should be understood that the frequency distributions represent the combined total number of passenger vehicles observed at all seven approaches at each point of reference. Since there was considerable variation in the observed speed ranges

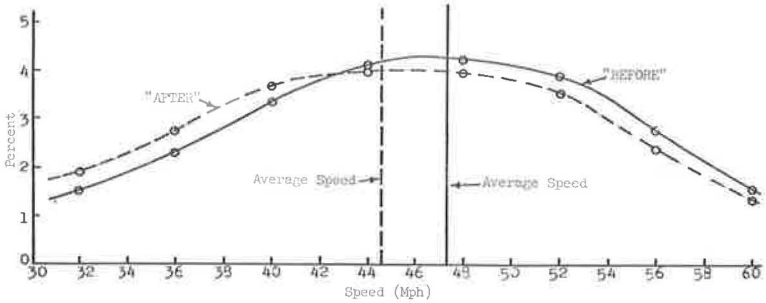


Figure 10. Approach speed frequency distribution 1500 feet from stop line.

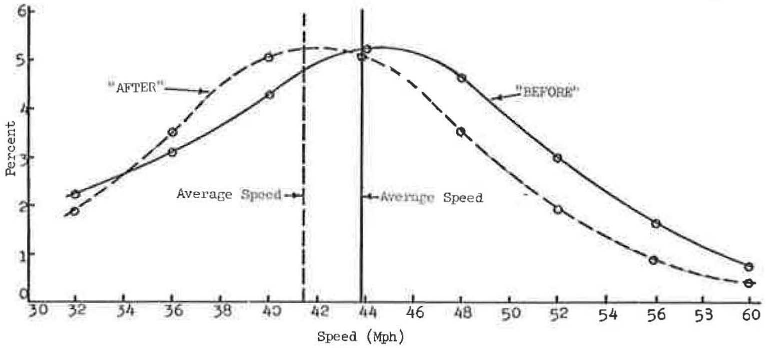


Figure 11. Approach speed frequency distribution 1000 feet from stop line.

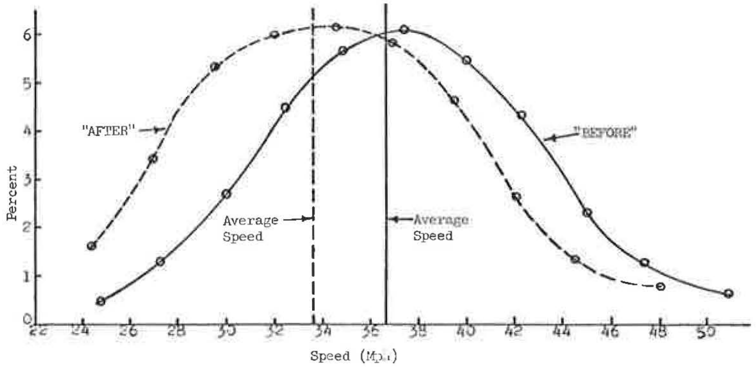


Figure 12. Approach speed frequency distribution 500 feet from stop line.

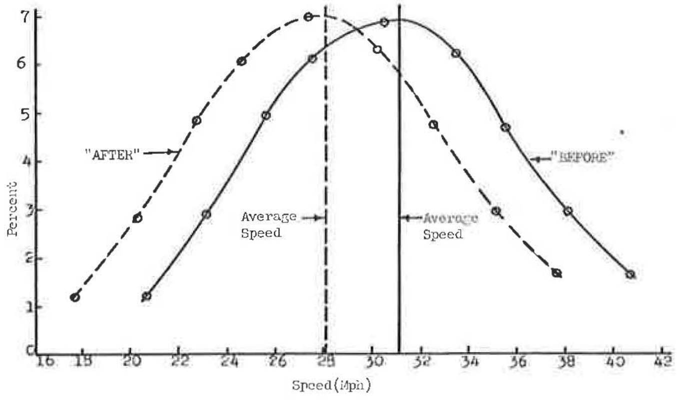


Figure 13. Approach speed frequency distribution 300 feet from stop line.

between the seven approaches in this study, no single approach can be expected to necessarily exhibit similar characteristics. The frequency distributions, however, are useful in demonstrating the decreasing trend in average speeds and the changes in dispersion at the various points.

The "before" curve in Figure 10 for the reference point 1,500 ft from the intersection shows a typical widely dispersed distribution as found on most rural highways. A reverse curve toward the "tails" of this distribution is just barely noticeable. The "after" curve shows the shift in mean accompanied by a slight increase in the dispersion. Figures 11, 12, and 13 indicate a progressively greater concentration of passenger cars around the mean together with an almost uniform decrease in the average speeds after the installation of the rumble strips. The dispersion is also slightly greater for the "after" condition in these distributions except in Figure 13 where the variance has not appreciably changed.

It was thought at the beginning of this study that the rumble strips might influence the skewness of the frequency curves. Very slight variations in skewness do occur, but it appears to be an entirely random phenomenon.

Stop Sign Observance

An important objective of this study was to determine the effect of rumble strips on traffic behavior. This was accomplished by recording the behavior of traffic with regard to stop sign observance before and after the rumble strip installations.

A negligible number of vehicles that flagrantly violated the stop controls were recorded at any of the locations either before or after the installation of the rumble

TABLE 6

STOP SIGN OBSERVANCE
(No. of Passenger Vehicles)

Category	Approach							Totals
	A_1	A_2	B	C	D	E	F	
				(Before)				
No stops and rolling stops	33	61	20	42	30	31	32	249
Full stops	34	29	10	11	32	14	17	147
Total	67	90	30	53	62	45	49	396
Percent no stops and rolling stops	49.3	67.8	66.7	79.3	48.4	68.8	65.3	62.8
Percent full stops	50.7	32.2	33.3	20.7	51.6	31.2	34.7	37.2
				(After)				
No stops and rolling stops	16	25	9	12	17	32	17	128
Full stops	29	48	22	42	40	9	31	221
Total	45	73	31	54	57	41	48	349
Percent no stops and rolling stops	35.6	34.2	29.0	22.2	29.8	78.0	35.4	36.7
Percent full stops	64.4	65.8	71.0	77.8	70.2	22.0	64.6	63.3

strips. These figures, therefore, were combined with the rolling stop data leaving two distinct groups: (a) those passenger vehicles that came to a complete stop, and (b) those passenger vehicles that did not stop as required by law (rolling stops and no stops). The results of the data recorded at each of the seven approaches are summarized in Table 6. Table 6 also contains the percentage of vehicles in each category both before and after the rumble strip installations. The data show a general increase in the percent of full stops for the "after" condition.

The Wilcoxon two-sample test was used to determine the significance of the increase in full stops by passenger vehicles after the installation of the rumble strips (4). This test of significance utilizes the method of ranking the percentage response for both the "before" and "after" conditions from the smallest to the largest. Thus, if the percentage of full stops is used, the ranks of the full stops would be large if the rumble strips are effective. The ranks are then applied to the Wilcoxon distribution to determine the significance. The Wilcoxon two-sample test is appropriate for the stop sign observance portion of this study because it gives the exact probability of whether or not a significant change has taken place as a result of the rumble strips.

The stop sign observance data were applied to the Wilcoxon distribution under the null hypothesis that the rumble strips would have no effect on the number of full stops. The probability of this event was found to be 0.00874, which definitely indicates the null hypothesis should be rejected. This means that the rumble strips increased the stop sign observance by passenger vehicles with greater than 99 percent confidence. The observed overall 26 percent increase in full stops after the installation of rumble strips is therefore highly significant.

Centerline Observance

A matter of concern in this study was that the rumble strips would cause approaching traffic to drive to the left of the centerline to avoid passing over the roughened sections of pavement. In order to measure this effect, centerline observance was recorded for approaching passenger vehicles before and after the installation of the

TABLE 7

CENTERLINE OBSERVANCE
(No. of Passenger Vehicles)

Category	Approach							Totals
	A_1	A_2	B	C	D	E	F	
(Before)								
Crossed centerline	0	0	4	0	0	0	4	8
Did not cross centerline	67	90	26	53	62	45	44	387
Total	67	90	30	53	62	45	48	395
(After)								
Crossed centerline	0	7	3	0	0	0	4	14
Did not cross centerline	45	66	28	54	57	41	45	336
Total	45	73	31	54	57	41	49	350

rumble strips. If any portion of the vehicle crossed the centerline during the stopping maneuver it was recorded as "crossed centerline."

A summary of the centerline observance data is given in Table 7, which indicates that for the "after" condition there was either no change or fewer violations of the approach centerline at all locations except Approach A_2. In view of this fact, the increase in centerline violations at Approach A_2 cannot be fully explained.

Since many of the approaches had no centerline violations either before or after the installation of the rumble strips, the ranking method of determining significance could not be used. Instead the data were classified into the two possible responses that could occur (i.e., whether the vehicles did or did not cross the centerline). A useful test for this type of classification is the Fisher-Irwin two-by-two table test (4). The null hypothesis that there are no more centerline violations after the installation of rumble strips than before has a hypergeometric distribution using the number of centerline violations for the "after" condition as a test value. Similar to the Wilcoxon two-sample

TABLE 8

ACCIDENT SUMMARY

Category	By Type						By Year					
	Before			After								
	Right Angle	Rear End	Fixed Object	Right Angle	Rear End	Fixed Object	1959	1960	1961	1962	1963	1964
Approaches A_1 and A_2 ("after" data from 10/1/62)												
Fatal	1	-	-	-	-	-	-	1	-	-	-	-
Personal injury only	3	-	-	1	-	-	1	1	-	1	1	-
Property damage only	4	-	-	1	-	-	1	1	1	1	-	1
Total	8	-	-	2	-	-	2	3	1	2	1	1
Approach B ("after" data from 7/1/64)												
Fatal	-	-	-	-	-	-	-	-	-	-	-	-
Personal injury only	-	-	5	-	-	-	-	1	3	-	1	-
Property damage only	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	-	5	-	-	-	-	1	3	-	1	-
Approach C ("after" data from 10/1/63)												
Fatal	-	-	-	-	-	-	-	-	-	-	-	-
Personal injury only	1	-	5	-	-	-	-	-	4	2	-	-
Property damage only	1	-	4	-	-	-	1	-	-	4	-	-
Total	2	-	9	-	-	-	1	-	4	6	-	-
Approach D ("after" data from 6/1/64)												
Fatal	-	-	1	-	-	-	-	-	1	-	-	-
Personal injury only	-	-	4	1	-	-	2	1	1	-	-	1
Property damage only	1	-	4	-	-	-	-	1	3	-	1	-
Total	1	-	9	1	-	-	2	2	5	-	1	1
Approach E ("after" data from 7/1/64)												
Fatal	-	-	-	-	-	-	-	-	-	-	-	-
Personal injury only	2	-	-	-	-	-	-	1	-	-	1	-
Property damage only	-	-	-	-	-	-	-	-	-	-	-	-
Total	2	-	-	-	-	-	-	1	-	-	1	-
Approach F ("after" data from 7/1/64)												
Fatal	-	-	-	-	-	-	-	-	-	-	-	-
Personal injury only	2	-	-	-	-	-	-	-	2	-	-	-
Property damage only	2	-	-	-	-	-	-	2	-	-	-	-
Total	4	-	-	-	-	-	-	2	2	-	-	-

test, the Fisher-Irwin test gives an exact probability using the normal approximation to the hypergeometric distribution. The probability that the observed 14 or more vehicles (Table 7) will cross the centerline was computed to be 0.1131. At the 5 percent significance level, therefore, the null hypothesis that there are no more centerline violations after the installation of rumble strips must be accepted. It may be concluded, then, that in this study the rumble strips did not change the pattern of passenger vehicle centerline violations.

Accident Frequency

The ultimate test of the effectiveness of rumble strips at rural stop locations is whether or not they bring about a reduction in accidents. To answer this question, all available accident records on file with the Minnesota Department of Highways Accident Records Section were analyzed. It was found that at all seven approaches a very sporadic frequency of accidents has occurred. No location has a constant frequency of accidents either by year or severity. This is probably due to the very low average daily traffic volumes at all of the study locations.

Table 8 summarizes the accident data for all study approaches by both severity and year from 1959 through 1964, and in "before" and "after" categories. Only accidents involving the approaches where rumble strips have been installed are included. Although no accidents have been reported at Approaches B, E, and F since the rumble strip installations, not enough time has elapsed to determine any trends. Approach D, which was also installed in 1964, has had one personal injury accident since the installation of rumble strips. This accident, however, occurred during a snowstorm.

Approaches A_1, A_2, and C have been installed for the longest period of time. Therefore, Table 9 was prepared to show individual accident comparisons at these locations. Approaches A_1 and A_2 represent a two-year "before" and "after" comparison, and Approach C represents a one-year comparison. In both cases the time periods have been chosen so as to include the same months and seasons in order to avoid any bias. No accidents, however, have been reported at either location since the "after" cutoff dates. The average daily traffic volumes have also remained constant at each location.

It can be seen (Table 9) that Approaches A_1 and A_2 show a 50 percent accident reduction for the two-year "before" and "after" period, while Approach C shows a 100 percent reduction for the one-year comparison. The "before" year at Approach C, however, had an abnormally high accident frequency so the six accidents shown do not reflect the normal rate. Although a decreasing trend in accidents is obvious, it would be unwise to determine any significance from this. Due to the erratic previous accident

TABLE 9

ACCIDENT TREND COMPARISONS

Type	Before				After			
	Fatal	Personal Injury	Property Damage	Total	Fatal	Personal Injury	Property Damage	Total
Approaches A_1 and A_2—2 Year Comparison (Before—10/1/60-9/30/62; After—10/1/62-9/30/64)								
Right Angle	-	1	3	4	-	1	1	2
Rear End	-	-	-	-	-	-	-	-
Fixed Object	-	-	-	-	-	-	-	-
Total	-	1	3	4	-	1	1	2
Approach C—1 Year Comparison (Before—10/1/62-9/30/63; After—10/1/63-9/30/64)								
Right Angle	-	1	-	1	-	-	-	-
Rear End	-	-	-	-	-	-	-	-
Fixed Object	-	2	3	5	-	-	-	-
Total	-	3	3	6	-	-	-	-

patterns, enough time has not elapsed in either comparison to determine reliable significance. Much more "after" accident experience must be gained before any definite conclusions may be drawn.

In summary, then, this study has shown a decreasing trend in accident frequency at Approaches A_1, A_2, and C, although no significance may be assumed at this time.

CONCLUSIONS AND RECOMMENDATIONS

In this study an investigation was made of the effect of rumble strips on traffic operation and behavior. Field studies were conducted at seven approaches to stop-controlled rural trunk highway intersections. Traffic operation and behavior were measured in terms of passenger vehicle speeds at predetermined points on the approaches together with stop sign and centerline observance studies.

The rumble strips consisted of a series of 25-ft long areas of rough-textured aggregate placed on the approach lanes at 50- to 100-foot intervals. The placing of the rumble strips in this study utilized four strips 25 ft long spaced 100 ft apart; six strips 25 ft long spaced 50 ft apart; and one at the intersection 50 ft long, which also acted as a nonskid treatment. The total length of the rumble area at each approach was 1,000 ft.

The field studies were conducted on a "before" and "after" basis during average weekday conditions. Effort was made to duplicate conditions so that uncontrollable or unknown factors could not influence the results.

The purpose of this study was to analyze a traffic control device that was expected to additionally alert drivers to the necessity of deceleration at rural stop locations and thereby cause safer operation at these locations. The major goals were (a) to effect a reduction in average approach speeds; (b) to increase the observance of the stop sign controls; and (c) to decrease the number of accidents involving approaching vehicles.

Results and Conclusions

Several important results were obtained from the mathematical analysis of the data. These, together with the conclusions which might be drawn from them, are as follows:

1. The three goals set forth appear to have been achieved. Rumble strips were found to have a significant influence on traffic speed and stop sign observance.
2. An overall consistent reduction in average approach speed was found at each point of observation.
3. The amount of dispersion (variance) about the average speed was found to be slightly larger in some cases after the installation of the rumble strips. The reason for the increase in dispersion was probably caused by some vehicles slowing down considerably more than others.
4. A highly significant increase in stop sign observance was found after the installation of the rumble strips. The use of audible stimuli tends to increase driver awareness of regulatory controls.
5. No appreciable change was found in the number of vehicles that drove to the left of the centerline to avoid passing over the roughened sections of pavement. The theory that rumble strips would have an adverse effect in this respect is apparently unfounded.
6. A decreasing trend in accidents was found at two rural intersections where rumble strips had been installed for a reasonable period of time. Due to the erratic previous accident patterns, however, enough time has not elapsed at either intersection to determine reliable significance. Rumble strips had been installed only a few months at the other study locations.

Recommendations

Additional research is recommended for the following reasons:

1. The data in this study represent Upper-Midwest driver reactions to rumble strips rather than those from a cross section of drivers throughout the nation. The assumption that all drivers will react identically may be erroneous.

2. The deceleration patterns of individual vehicles have not been investigated in this study. Simultaneous speed checks should be made to discover if rumble strips cause any changes in these patterns.
3. Because of generally low traffic volumes, not enough truck data were collected for proper analysis. Data should be collected at a location with sufficient commercial vehicles to determine if similar results are obtained.
4. This study represents daytime conditions only. It is not known if rumble strips would have a different effect on traffic during periods of darkness.
5. Additional experimentation should be done as to the length and spacing of the rumble panels. It is felt that an optimum design can be developed for maximum effect on traffic operation.
6. The rumble strips in this study required considerable maintenance and periodic patching. Materials research is needed to overcome these problems.
7. It would be desirable to experiment with a series of other locations where rumble strips might be used as a traffic control device. This method of control, however, should be limited to special locations. Over-usage could defeat its intent. Warrants for rumble strips installations could be established from this type of research.

REFERENCES

1. Rumble Strips at Hazardous Locations. Better Roads, Vol. 35, No. 1, Jan. 1964, pp. 16-21.
2. Cook County Highways. Vol. 8, No. 6, Nov. 1960, p. 6.
3. Dixon, Wilfrid J., and Massey, Frank J., Jr. Introduction to Statistical Analysis, Second Ed. McGraw-Hill, New York, 1957, p. 139.
4. Hodges, J. L., and Lehman, E. L. Basic Concepts of Probability and Statistics. Holden-Day Inc., San Francisco, 1964.
5. Kermit, Mark L., and Hein, T. C. Effect of Rumble Strips on Traffic Control and Driver Behavior. HRB Proc., Vol. 41, 1962, pp. 469-482.
6. Manual of Traffic Engineering Studies, Second Ed. Assn. of Casualty and Surety Cos., New York, 1953.
7. Manual on Uniform Traffic Control Devices for Streets and Highways. U.S. Bureau of Public Roads, Washington, 1961.
8. Matson, T. M., Smith, W. S., and Hurd, F. W. Traffic Engineering. McGraw-Hill, New York, 1955, p. 22.
9. Minnesota Motor Vehicle and Traffic Laws. Minn. Dept. of Highways, St. Paul, 1963.
10. Moroney, M. J. Facts From Figures. Penguin Books Inc., Baltimore, 1951.
11. Norman, O. K. Preliminary Results of Highway Capacity Studies. Public Roads, Vol. 19, No. 12, 1939, pp. 227-228.
12. Puy-Huarte, Jose. The Effect of Transverse Strips on Vehicle Operation. Unpublished Master's thesis, Ohio State Univ., 1962.
13. Traffic Safety. Vol. 65, No. 3, March 1965, pp. 28-29.
14. Votaw, David F., Jr., and Levinson, Herbert S. Elementary Sampling for Traffic Engineers. Eno Foundation for Highway Traffic Control, Saugatuck, Conn., 1962.

Evaluation and Improvement of Traffic Signal Settings by Simulation

STEPHEN B. MILLER, Aerospace Corporation, El Segundo, California, and
JOHN D. C. LITTLE, Operations Research Center,
Massachusetts Institute of Technology

Several methods of setting traffic signals are studied by means of traffic simulation. A test problem, consisting of a six-signal network in Boston, is used to compare three methods: (a) maximal bandwidth progression, (b) "simswitch" (in which the center of red is simultaneous along all parallel streets), and (c) random search (choosing the best of a number of randomly selected settings). Performance is measured as a weighted combination of average delay per vehicle and average number of stops per vehicle. Two systematic procedures for improving a given setting are explored. Both involve one-variable-at-a-time search in the neighborhood of the original setting. In the first, the absolute offset of an individual signal is the changed variable; in the second, the relative offset between a pair of adjacent signals is changed.

The conclusions are reached that (a) operationally significant differences exist among settings that a priori might be expected to be good ones; (b) the criterion adopted for evaluating performance substantially affects which setting will be chosen; (c) many traffic situations do not conform to the simplest models and it is difficult to predict good settings without detailed examination of traffic movement as through simulation; (d) an effective way to obtain good settings through simulation may be to test out several settings considered in advance to be good and then improve the best one or two by systematic search; (e) performance is flow-dependent, i. e., a setting good at one level may be poor at another even though the patterns of flow are similar; and (f) settings with progressive timing seem more likely to be degraded in performance by turning vehicles than are systems with simultaneous switching.

•THE PROBLEM of traffic congestion in urban areas shows little sign of early abatement or easy solution. To a considerable degree this is because improved facilities generate increased use, but as long as benefits exceed total cost, the gains can be welcomed. Traffic congestion can be reduced by building new roads, by improving public transit facilities, or by improving the utilization of the current road system. The present paper concentrates on this last possibility. Even small percentage improvements in existing systems can have substantial significance when one considers alternative ways to achieve the same effect through new facilities.

In trying to improve traffic operations, we are concerned with the driver's convenience and safety. Convenience is represented by few stops, little wait when stopped, short trip times, and, as a means to an end, by high flow rates in the system. Safety

---

Paper sponsored by Committee on Traffic Control Devices and presented at the 46th Annual Meeting.

is affected by many factors, including a number of characteristics of traffic flow. Several studies (1, 2, 3) have shown that accident rates increase with traffic flow and congestion and generally with the demands imposed on the driver.

Traffic signals usually do not by themselves reduce accidents at an intersection (4). In fact, certain types of accidents, e. g., rear-end collisions, are increased. However, studies have shown that fatal accidents usually decrease when signals are installed and also that the accident rate for high vehicular flow is less with signals than without them (5). Since traffic signals are obviously necessary at many intersections, it is reasonable to ask if some signal settings result in fewer accidents than others. Studies (1, 3) have shown that rear-end collision rate is proportional to the number of stops required. A successful progression system will reduce stops and is therefore likely to reduce the rear-end collision rate. Two studies (6, 7) have shown that a high quality of flow and a low accident rate go together. High quality of flow is associated with a high average speed, infrequent changes of speed, and, when changes occur, changes of moderate size. These flow characteristics are closely related to the driver's desired traffic conditions so that improvements in signal settings from the point of view of driver convenience may frequently reduce accidents as well.

Perhaps the ideal way to set traffic signals would be to instrument a street network so as to measure stops, waits and trip times continuously and then, by extensive experimentation, find the control procedure that maximizes the effectiveness of the system as a whole. Some modern traffic control systems with detectors in the streets and computer control of the signals begin to approach the desired instrumentation (8, 9). However, even where good instrumentation exists, it is doubtful that on-street experimentation could search through the tremendous number of control possibilities without some sort of off-street theory to identify the relevant choices.

From the standpoint of realism the next best thing to instrumentation would be an accurate simulation of traffic movement on the street network. With simulation, traffic control systems can be evaluated on a computer instead of on the street. As simulated cars pass through a street network, their stops and delays are easily recorded for evaluation purposes. However, simulations frequently consume large amounts of computation time. Efficient search methods for evaluating the many possible control procedures need to be devised. Some possible methods are investigated in this paper.

Another class of models used to determine traffic signal settings is aimed specifically toward optimization. Detail in the traffic flow assumptions is sacrificed to make possible efficient search for the best setting. The model and the criteria to be optimized are usually fairly simple and are selected with the objective of capturing the essential features of the problem. An example of this approach is the maximal bandwidth algorithms of Morgan and Little (10) and Little (11). Such models permit finding exact optima, but their traffic assumptions and criteria must be examined for relevance in the particular situation. The value of these solutions can be examined by observing them on the street, or by testing them in a simulation. Examples of the latter are given here.

The decreasing cost of computation coupled with the importance of the traffic control problem has brought about computer-controlled traffic systems in a number of cities (8, 9). Such systems permit real-time control on both an individual intersection and area-wide basis; i. e., vehicle detectors in the streets provide information with which to set the signals more or less immediately and continuously. In the present paper we shall not explore the potentialities of this type of control but rather will concentrate on fixed-time systems. The reasons are twofold. In the first place many cities, by virtue of size, traffic conditions, or financial conditions, will not justify computer-controlled systems very soon. Secondly, computer-controlled systems presently work to a considerable extent from tables of fixed-time settings, an appropriate table being selected by the computer according to traffic conditions.

A SIMULATION MODEL

Many different levels of detail are possible in a simulation of traffic. For computational efficiency, one seeks the least detail that will still reproduce the most important features of traffic. Just what model does this is probably yet to be determined. Among the simulation models so far reported are those of Gerlough and Wagner (12), Katz (13), Kell (14), and Blum (15). The model here is that of Schwartz (16), modified slightly. The model is a fairly simple one. Its general features are outlined below. A more detailed description and a discussion of model predictions versus observations may be found in the original report (16).

In Schwartz's simulation each vehicle that enters the system is modeled explicitly. Each is generated at some point on the boundary of the network. There is some flexibility in the method of generating the vehicles. The examples here use either exponentially distributed interarrival times between vehicles or constant interarrival times, but other schemes, including the arrival of platoons, can be used.

As soon as a vehicle enters the network and each time a vehicle reaches an intersection, a probabilistic decision is made to determine whether the vehicle will go straight ahead or turn right or left. The values of these probabilities are determined from field observations on the actual network. After leaving an intersection, a vehicle is held in a delay "store" for the amount of time required for it to move to the next intersection. This time is determined by the vehicle's speed and the distance to be traveled. When the vehicle reaches the intersection, it chooses its next link and, if there is no queue and the signal is green, goes through. If there is a queue, the vehicle takes a place at the rear of the queue. If the signal is red, the vehicle waits at the intersection or at the end of the queue, as the case may be. In order to simulate the startup delay that occurs just after a signal turns green, the program retards the advance of any waiting queue for two seconds.

In practice the simulation program models a single generalized intersection and a single generalized link. (A link is defined as a street segment between two adjacent intersections along with a direction of travel on the segment.) Parameters and state variables for individual intersections are entered in tables. State variables are changed and updated for each link, signal light and intersection in each elemental time period (one second in the work here).

In Schwartz's original program, the time to traverse a link was a constant for the link. This means there is no diffusion of traffic platoons or disruption of smooth flow. In practice, as vehicles move away from a recently changed signal, the vehicles in front usually pull away from the bulk of the platoon. Cars toward the rear lag behind. A simulation model that ignored diffusion may make certain ways of setting the signals, e. g., maximal bandwidth methods, look better than they actually are. Accordingly, it was desired to modify the model to include this phenomenon.

One simple way to model diffusion is to let vehicle speeds, instead of being constant, follow a normal probability distribution (17, 18). Although this implicitly assumes free passing and a speed independent of position in the platoon, actual traffic observations show reasonable agreement between model and fact except in conditions of heavy flow. The coefficient of variation (the standard deviation of speeds divided by mean speed) is almost constant at about 0. 15 for moderate flow rates. In the modified version of the program the speed of a vehicle on a link is chosen from a normal distribution with the above coefficient of variation and a mean speed based on observation of traffic on the link.

The output of the simulation program includes the total number of vehicles that have entered and left the network, total number of stops, and the total delay for all vehicles that have left the network. Delay to a vehicle on a link is calculated as the time spent on the link over and above the time that would be required to travel the link at the vehicle's chosen speed. In addition the number of cars to enter each link and the average time these cars spend on the link is available. Other measures of performance can be made available.

The running times of the simulation depend on the number of signals and on the input flows. Schwartz's runs on a 26-signal network were about one-half of real time on an IBM 7094. Our runs on a 6-signal network were about one-sixth of real time on the same computer. Quite likely a considerably more efficient program could be written if the effort were devoted to it.

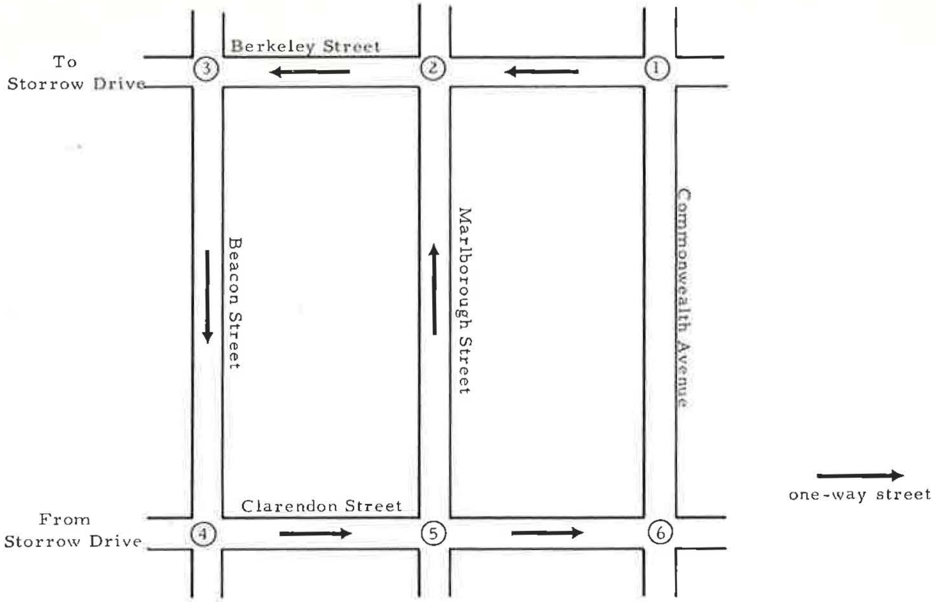


Figure 1. Section of Boston Back Bay used as a test problem (signals are numbered as in text).

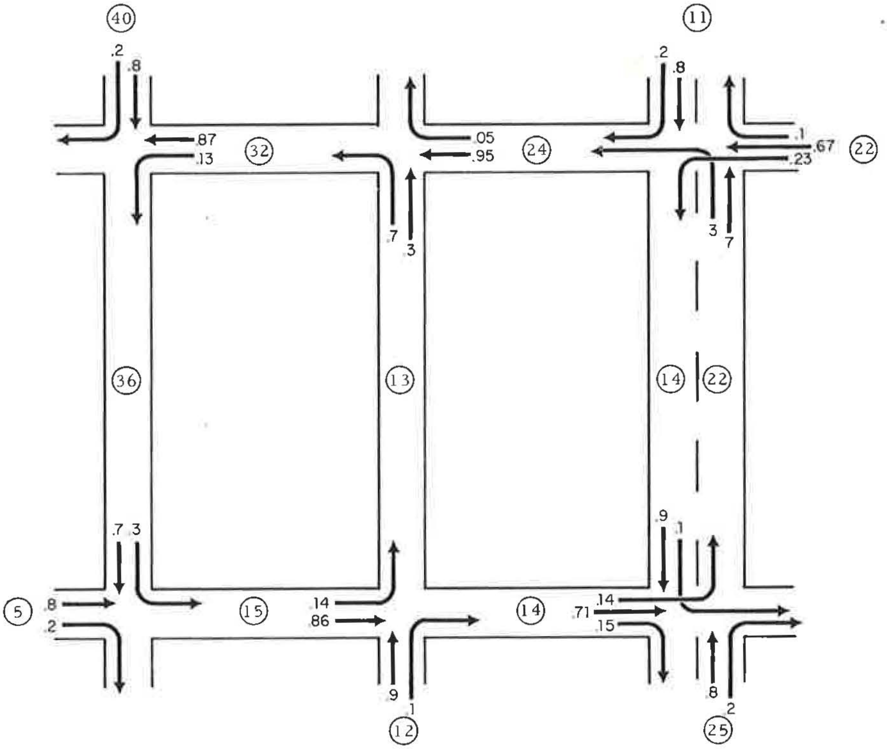


Figure 2. Network parameters for medium traffic flow. Flows are average vehicles/cycle as observed on a weekday early afternoon. Cycle length was 116 seconds.

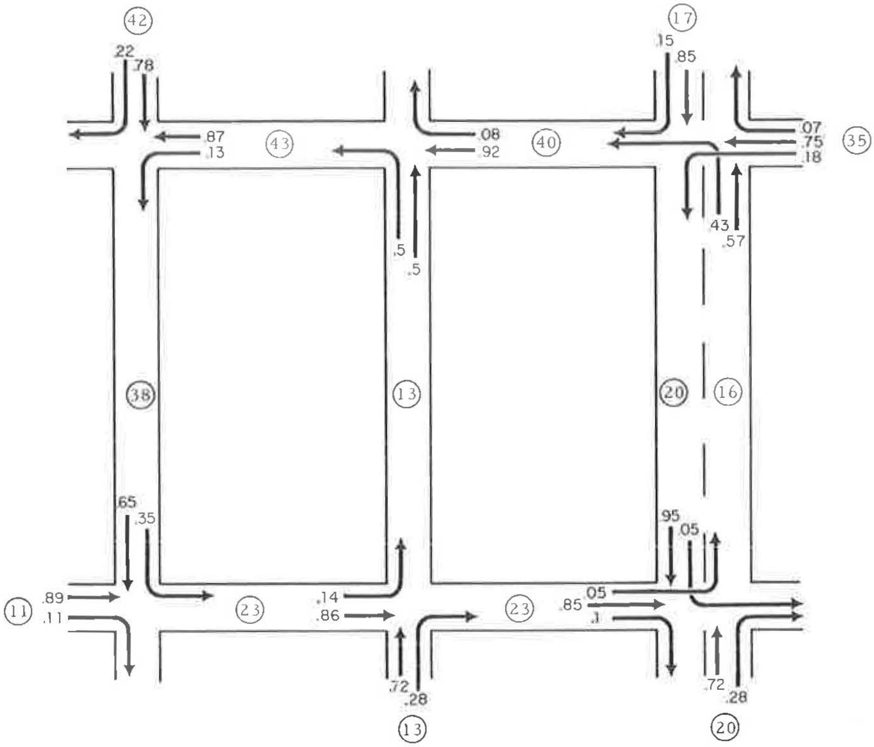


Figure 3. Network parameters for heavy traffic flow. Flows are average vehicles/cycles as observed during a weekday evening rush hour. Cycle length was 105 seconds.

CRITERIA

In order to evaluate a signal setting, some measure of performance, or criterion, is necessary. There are a number of possibilities; stops, wait while stopped, trip delay, and safety are examples. Helly (19) has discussed "acceleration noise," a measure of unevenness in speed. Another possibility is throughput, particularly throughput at peak periods when congested streets represent a reservoir of unsatisfied demand. Certainly any change that will increase flow at such times is highly desirable. However, any increase in throughput will immediately be reflected in driver-oriented criteria and so these are what we shall use.

The driver's tradeoffs among criteria have not, to our knowledge, been probed in an operational way. Some system changes will improve performance by several criteria. However, as will be demonstrated, it is possible to find examples where number of stops goes up and delay goes down and vice versa. Thus, we really would like to know the driver's tradeoffs. Since these are lacking, we shall do two things: in some cases we shall display multiple criteria, in others we shall make reasonable but arbitrary combinations of criteria, focusing on stops and trip delay.

The model calculates stops under the assumption that the driver, when obstructed by a red light or a queue, maintains his desired speed until the last moment and then stops abruptly. In practice, of course, drivers slow down if they see an obstruction and sometimes may not stop at all, different drivers having different habits. Accordingly, the number of stops calculated by the simulation overestimates the actual number of times a vehicle would become stationary on the street but correctly characterizes the number of times a vehicle is obstructed.

The calculated delay is trip delay, the difference between the time a driver spends on a link and the time he would spend if he traveled at his desired speed. This is also the wait while stopped under the assumptions of the model although, for the reasons mentioned, it would be an overestimate of the stopped time that would occur on the street.

Our intutitive belief is that drivers would tolerate some added trip delay in order to decrease the irritation represented by stops and obstructions. Accordingly, we have chosen an overall criterion that is a weighted sum of stops and delay. Where a specific number is required, we shall take one stop as equivalent to 15 seconds of trip delay.

Certain traffic phenomena are not included in the present simulation model. Delays that result when a vehicle makes a left turn across opposing traffic are not represented. There is no speed-density relation included nor is there any slowdown process as a vehicle approaches a queue or red signal. However, this model does consider the possibility that a link may become too full for more vehicles to enter.

TEST PROBLEM

A specific network of streets has been chosen for study. Although the simulation program is general, runs can only be made after specializing the program to a given network with specific flows, turning percentages, one-way streets, etc. The results we obtain with our network may or may not be representative of others. One might try to construct a "typical" network but it seems doubtful that meaningful general results could be obtained, because real situations tend to have individual peculiarities. Instead we take a specific example. It will demonstrate the feasibility of the techniques and will give some impression of what types of results can occur.

The test problem is a 5-street, 6-signal network drawn from Boston's Back Bay section (Fig. 1). The problem is small enough that multiple exploratory runs can be made within a reasonable amount of computer time and yet the problem still contains certain interesting complexities. The network has two interdependent loops. The six signals, each of which affects the flow on two streets, provide quite a few decision variables. Commonwealth, Berkeley, and Beacon carry traffic to and from the downtown area and have reasonably heavy flows during rush hours. Commonwealth has a pedestrian red-red phase. Both one- and two-way streets are included; in fact, four of the five streets are one-way. While this may seem like a large number, it turns out that almost all the streets in downtown Boston are one-way and this is the case in many cities. Thus, this type of network seems very worthy of study.

Field observations were made to determine the average input flows and turn probabilities needed by the simulation. Data were collected for the evening rush hour, called here "heavy flow" and for weekday early afternoon, called "medium flow." In addition a "light flow" was defined by taking one-half the medium flow values. Figures 2 and 3 show the turn probabilities and flow on each link for high and medium flow.

METHODS OF SETTING SIGNALS

Finding the exactly optimal fixed-time setting for a complex model of a network of signals is a formidable mathematical and computational problem. The decision variables are numerous—each signal has a green split and an offset and the network as a whole has a period. Some signals may have more complex phases such as left turn arrows or pedestrian signals. We do not know how to solve this problem exactly, but we wish to examine what appear to be sensible approaches. Most of the emphasis will be on finding offsets, although some of our runs concern other aspects and our general search techniques apply to any set of variables.

The traffic signal problem is characterized by multiple local minima. In other words, if one takes a given setting and systematically makes small changes in each control variable, retaining changes that are improvements, and continuing the process until any small change only worsens the solution, a local minimum is, by definition, achieved. However, a different starting setting can lead to a different local minimum, which may be better or worse than the first. Neither is necessarily the global minimum, i. e., the smallest of all local minima.

In the case of maximal bandwidth settings, the criterion and model are sufficiently simple that exact methods are available for sorting through the local minima to find the global minimum. For the relatively complex model of the simulation, no theory presently exists to do this. One might conjecture that a good local minimum would exist in the neighborhood of, say, the maximal bandwidth setting, but such a conjecture would have to be tested.

This suggests the following approach: Find starting settings that would be expected to be good, evaluate them by simulation, and then apply to the best of them some systematic improvement procedure. Accordingly, in this section we discuss methods of determining starting settings and, in the next, improvement techniques.

The methods that we take up for finding starting settings are: maximal bandwidth, simswitch, and random search. This list is not exhaustive; a good setting might come from anywhere. However, each of these techniques is generally applicable.

Maximal Bandwidth

The concept of a progression is widely used in synchronizing signals. The bandwidth of a progression in a given direction on a given street is that fraction of the cycle during which a vehicle could start at one end and, by traveling at designated speeds, go to the other end without stopping. The concept of a progression was conceived for arteries but it can be extended to networks.

In a network each direction on each street has its own bandwidth. To resolve conflicts among bandwidths, our mathematical program for the problem takes a weighted sum of bandwidths as the objective function. In order to keep the bandwidth on some streets from becoming too small, we shall require all bandwidths to be at least some fraction of the most heavily weighted bandwidth. One must be careful in this not to impose constraints that allow no feasible solution.

In determining maximal bandwidth settings we shall allow the design speed of the progression to vary within certain limits. This permits some recognition of the fact that the simulation does not use a single speed on the street. The period is also a variable of the problem and its value is chosen to maximize the objective function. The mathematical program can be formulated with the green splits as control variables as well, but in the work here we have not done this. Effective green time is divided between streets so that the ratio of green times is the ratio of their values of flow/saturation flow, i. e., Webster's equation (20).

The method for solving for signal settings to give maximal bandwidth is described elsewhere (11). For the Back Bay problem the mathematical program has 36 linear equations and involves 3 integer and 29 continuous variables. Its solution by branch and bound methods required solving 8 ordinary linear programs. The equations and the solution tree are given by Miller (22).

The maximal bandwidth program was solved for the medium traffic case. Since light flow is everywhere half of medium flow, the same solution will apply there. The heavy flow has a slightly different pattern and so possibly a different solution. However, we arbitrarily use the same settings in the work to follow.

Simswitch

Progressions are generally considered appropriate for low and moderate flows, but at high flows the building up of queues during red tends to obstruct a platoon timed to arrive just as the signal changes to green. One approach to this situation is to make all the signals on a street green at the same time. Then all the platoons travel at once and do not interfere. Of course, the long traverses without stops that might be possible in a progression system cannot be made.

This simultaneous green procedure will be called "simswitch." It is primarily appropriate for rectangular grids. If all the green splits are the same, the signals turn green exactly together (except for pedestrian red-red and other special phases) and the system has only two parameters: green split and period. We shall call this case "simswitch 1." As another possibility, green time may be divided between streets

TABLE 1

MAXIMAL BANDWIDTH AND SIMSWITCH 1 RUNS
(575 seconds, exponential interarrival time input)

Setting	Flow	Average Delay per Vehicle (seconds)	Average Stops per Vehicle (stops)
Maximal bandwidth (50-second period)	Low	20	1.09
	Medium	23	1.00
	Heavy	32	1.08
Simswitch 1 (50-second period)	Low	22	0.86
	Medium	25	0.97
	Heavy	40	1.27
Simswitch 1 (100-second period)	Low	31	0.83
	Medium	36	0.86
	Heavy	52	1.02

proportional to flow/saturation flow. Then period is the only parameter. This case will be called "simswitch 2." The centers of the red periods will be made to coincide for signals on parallel streets.

Simulation Results

Simulation runs have been made for all three flows with the maximal bandwidth settings and with two simswitch 1 settings, the first having a 50-second period, the second a 100-second period. Both simswitches employed equal green times in each direction. The traffic input at the edges of the network was Poisson (i.e., exponentially distributed interarrival times). All runs were for 575 seconds of street time, of which the first 50 seconds were ignored so as to allow the network to fill with cars. The results in terms of average delay per vehicle and average stops per vehicle are given in Table 1 and Figure 4.

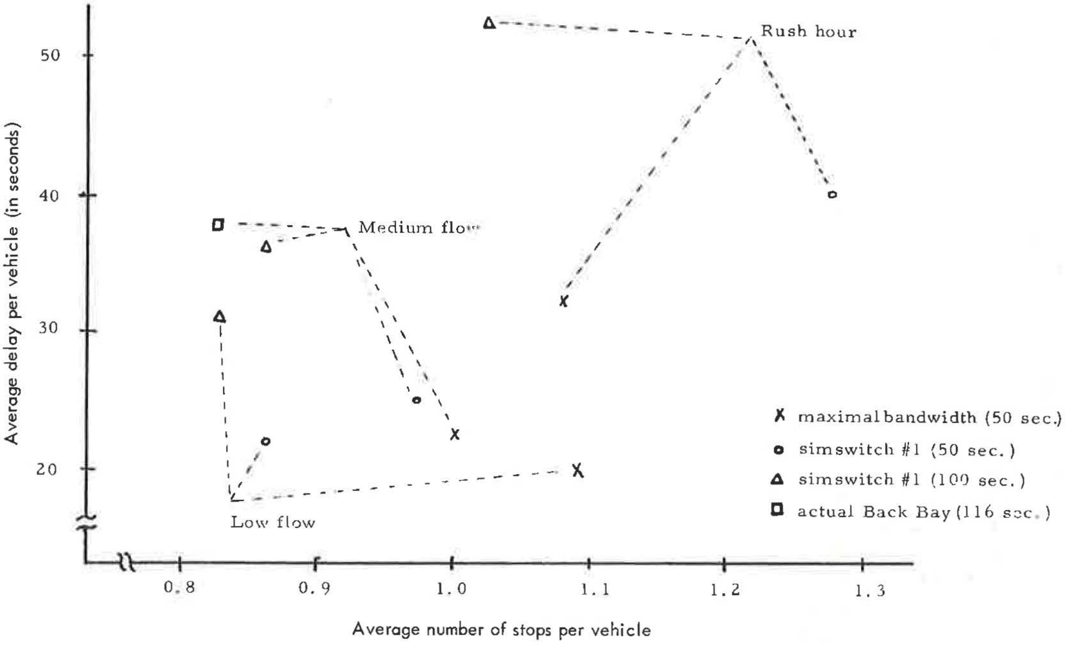


Figure 4. Values of performance measures for various signal settings and traffic flows.

The first observation to make is that the choice of performance criterion affects the choice of setting. For example, at heavy flow, if delay is disregarded and stops are the criterion, the 100-second simswitch 1 is best; whereas for the reverse situation maximal bandwidth is best. Similar situations occur at other flows.

If we adopt the trade-off relation of 1 stop = 15 seconds delay, the best settings are

low flow:	50-second simswitch 1
medium flow:	maximal bandwidth
heavy flow:	maximal bandwidth

These results are not necessarily what one would expect. Maximal bandwidth progressions would be expected to be good at low flows, simultaneous switching at high ones. Some of this can be explained retrospectively by examining the specific situations involved. More important, however, these results suggest that it is difficult to predict good settings without a detailed examination of traffic movement as through a simulation.

A result that conforms to expectations is that the longer period simswitch gives more delay but fewer stops. The driver can go farther during green without stopping but once stopped must wait for a longer red.

Random Search

Because of the existence of local minima, there may be an advantage to generating a variety of different settings and evaluating them by simulation. A common way to generate a large number of different solutions in mathematical programming problems is to select values for the variables by a random process. In the present situation, offsets (in seconds) for signals with periods of 100 seconds or less can be taken directly from 2-digit random number tables, discarding values that are too large.

Random generation of settings has two interesting advantages. First of all, it is quite free of preconceived notions. It will explore unconventional settings good and bad and, from time to time, will produce rather effective new approaches. Second, after a number of settings have been run, a statistical estimate can be made of the chances of improving the results further.

As an example, 12 runs have been made with random offsets under the following conditions: medium flow, 50-second period, constant interarrival times for entering vehicles, and a run length of 200 seconds of street time, the first 100 ignored in calculating the objective function. The objective function uses the trade-off of one stop equals 15 seconds delay. The calculation is: objective function = (average delay in seconds/vehicle) + (15 seconds/stop) (average stops/vehicle).

Table 2 gives the results. The objective function ranges from 39. 0 to 65. 1 seconds/vehicle with a mean of 47. 2 and a standard deviation of 6. 8. The standard deviation makes possible an estimate of how hard it is to improve the run by a given amount through further random search. Thus, if the distribution of objective function values is assumed to be normal with the mean and standard deviation given, there is one chance in 20 that another run would be 36. 0 or better.

For comparison, a maximal bandwidth run under the same conditions gives 42. 4 seconds/vehicle. Thus, the best of the 12 random settings is about 8 percent better. This will not always happen, however. Under another set of operating conditions, the maximal bandwidth setting gave 4 percent better than the best of (a different) 12 random settings.

Random search is not a very elegant method and its usefulness is strongly dependent on the speed of the simulation because it is necessary to pick through many bad settings to find the good ones. However, random search is easy to do and with a fast simulation may well be competitive with other methods.

TABLE 2

12 RANDOM OFFSET RUNS
(200 seconds, medium flow, constant interarrival time input,
50-second period)

Run	Objective Function (seconds/vehicle)	Run	Objective Function (seconds/vehicle)
1	49.2	7	44.6
2	39.5	8	65.1
3	44.7	9	39.0
4	46.5	10	44.0
5	52.6	11	50.0
6	45.1	12	46.0

Mean: 47.2 seconds/vehicle Standard deviation: 6.8 seconds/vehicle

Other Runs

A number of additional runs have been made.

Actual Back Bay Settings—For completeness, the green splits, period, and offsets currently in use at medium flow in Back Bay have been run. The result is plotted in Figure 4. The point is of interest as another possible setting in the test problem, but is not necessarily a good evaluation of the setting in actual practice. The reason is that our study condition isolates the test area with respect to timing of flows (i. e., platoon arrivals) although not their magnitude. This was necessary because otherwise it would be almost meaningless to vary period in the test problem.

Sensitivity of Maximal Bandwidth Calculation—If the maximal bandwidth calculation is sensitive to its input constants and if inaccurate constants are used, the resulting settings might be very poor. As some test of this possibility, a maximal bandwidth calculation has been made with green splits changed 20 percent and the speed range shifted from 30-36 ft/sec to 33-39 ft/sec. (The mean speed in the simulation is 33 ft/sec.) Other constants have been left alone. A very different setting emerges, although the objective function of the mathematical program is not much changed. When the setting is used in the simulation, the number of stops is unchanged and the delay increases only 5 percent. Thus, at least in this one case, although the settings are sensitive, the criterion does not change much.

Effect of Modeling Diffusion—Several runs have been made comparing the original Schwartz simulation to the present version, which include platoon dispersion. Little effect on average stops or delay is observed. However, the dispersion model has been kept in the program.

Simswitch 2—As described earlier, this setting was green splits determined by Webster's equation. The results are inferior to those of simswitch 1 on our test problem. We note, however, that Schwartz (16) in his simulation of Back Bay as a whole found simswitch 2 somewhat better.

Effect of Turning Vehicles—Progression systems cater to vehicles that go straight through the intersections. In our network an average of about 20 percent of the vehicles turn upon entering an intersection. This may degrade the performance of the maximal bandwidth setting. To investigate this, two runs were made at low flow with turns eliminated, one with the maximal bandwidth setting and the other with simswitch 1. The maximal bandwidth run showed a 25 percent reduction in average delay and 29 percent reduction in average stops. In contrast, simswitch 1 showed 9 percent reduction in each. This helps explain the somewhat surprising result found earlier that simswitch 1 was superior to maximal bandwidth at low flows.

IMPROVEMENT TECHNIQUES

We consider next the possibility of improving a given setting. One important approach is to inspect the computer output, looking for trouble spots and making changes.

Beyond this, however, it seems desirable to develop systematic improvement methods. Many techniques have been proposed for optimizing a function of several variables. One of the simplest techniques and frequently a rather effective one is one-variable-at-a-time search, called by Leon (21) "univar." We shall describe a univar algorithm, discuss two ways of applying it to the improvement of offsets, and report our computational experience.

A Univar Algorithm

Let $x_1, \ldots, x_n$ be the variables to be chosen and let the goal be to minimize an objection function, $f(x_1, \ldots, x_n)$ (here calculated by simulation). The steps to be taken are:

1. Set the x_j to their starting values.
2. Calculate $f(x_1, \ldots, x_n)$. Set BVSF (= best value so far) to $f(x_1, \ldots, x_n)$ and IBVSF (= index of variable whose change caused BVSF to be reset) to 1.
3. Set $i = 1$.
4. Increase x_i to $x_i + \Delta_i$, where Δ_i is the increment chosen for increasing and decreasing x_i. Calculate $f(x_1, \ldots, x_n)$. If its value is less than BVSF, reset BVSF to the new value, reset IBVSF to i, and restart step 4. Otherwise reduce x_i by Δ_i (i. e., to its prévious value) and continue.
5. If any improvement was made in step 4, go to step 7. Otherwise continue.
6. Decrease x_i to $x_i - \Delta_i$. Calculate $f(x_1, \ldots, x_n)$. If its value is less than BVSF, reset BVSF to the new value, reset IBVSF to i and restart step 6. Otherwise increase x_i by Δ_i and continue.
7. If $i < n$, set i to $i + 1$. Otherwise set $i = 1$.
8. If $i \neq$ IBVSF, return to step 4. Otherwise, there has been no improvement in one full cycle through all n variables and we are finished.

A few remarks may be added. No upper and lower bounds have been placed on the x_i but this would not be difficult to do. Bounds are not necessary for offsets because offsets are treated modulo the period. Although the algorithm could be programmed, it is so simple that our practice has been to perform it by hand, doing only the simulation on the computer. The process can be stopped before the end if improvements become infrequent. Since the simulation uses random numbers to determine certain car movements and since only a finite time sample is run, it is possible that a local minimum could be produced by a statistical fluctuation. This does not appear to have been a problem in our runs, and it has been our choice to accept this possibility rather than, say, extend the region of search beyond the point where the objective function first starts to increase.

The results of applying univar to the best of the 12 random settings reported in Table 2 are given in Table 3. The offsets have been changed in the order of their signal numbers, although this is not required. Run conditions are the same except for changing offsets. The objective function is reduced from 39. 0 seconds/vehicle to 36. 5 seconds/vehicle, an improvement of about 6 percent. Twenty-one simulations have been used. We conclude that the method is capable of finding moderate improvements, even in relatively good settings. We conjecture that most of the effect is in the first iteration through all the offsets.

Several other univar runs have been made on various starting settings under various run conditions. These were all stopped after a single iteration and usually showed improvements in the 7-10 percent range.

Choice of Variables

We wish now to distinguish between two ways of using univar. They will be called changing one signal at a time and changing a group. The distinction and its relevance are clearest in an arterial problem. Suppose the absolute offset of a signal, S_j, in the middle of an artery is changed. This has the effect of changing two important relative offsets, the ones relative to the adjacent signals on either side of S_j. In a real sense, we have changed two important variables at once, not one. If we wish to vary just

TABLE 3

APPLICATION OF UNIVAR ALGORITHM TO IMPROVE OFFSETS
(One-signal-at-a-time Method)

Run No.	Offsets (sec) for Signal No.: 1	2	3	4	5	6	Objective Function (sec/vehicle)	Is this a new minimum?
Original	13	23	29	41	25	36	39. 0	
2	15	23	29	41	25	36	41. 5	no
3	11	23	29	41	25	36	38. 1	yes
4	9	23	29	41	25	36	40. 8	no
5	11	25	29	41	25	36	42. 3	no
6	11	21	29	41	25	36	40. 8	no
7	11	23	31	41	25	36	41. 6	no
8	11	23	27	41	25	36	36. 8	yes
9	11	23	25	41	25	36	40. 3	no
10	11	23	27	43	25	36	36. 5	yes (best value)
11	11	23	27	45	25	36	37. 6	no
12	11	23	27	43	27	36	39. 5	no
13	11	23	27	43	23	36	39. 7	no
14	11	23	27	43	25	38	37. 9	no
15	11	23	27	43	25	34	36. 9	no
Second Iteration								
16	13	23	27	43	25	34	38. 3	no
17	9	23	27	43	25	34	37. 8	no
18	11	25	27	43	25	34	39. 7	no
19	11	21	27	43	25	34	40. 0	no
20	11	23	29	43	25	34	38. 7	no
21	11	23	25	43	25	34	40. 4	no

$$\text{Improvement} = \frac{39.0 - 36.5}{39.0} = 6.4\ \%$$

Note: There is no reason to continue the second iteration beyond run No. 21 because we have returned to the same set of signal offsets as existed in run No. 10. From No. 22 on the results would be exactly the same as those for runs following run No. 10.

TABLE 4

APPLICATION OF UNIVAR ALGORITHM
(Group Method)

Run No.	Offsets (sec) for Signal No.: 6	1	2	3	4	5	Objective Function (sec/vehicle)	Is this a new minimum?
Original	36	13	23	29	41	25	39. 0	
2	36	15	25	31	43	27	37. 5	yes
3	36	17	27	33	45	29	36. 7	yes (best value)
4	36	19	29	35	47	31	38. 6	no
5	36	17	29	35	47	31	45. 2	no
6	36	17	25	31	43	27	50. 3	no
7	36	17	27	35	47	31	40. 9	no
8	36	17	27	31	43	27	41. 0	no
9	36	17	27	33	47	31	39. 9	no
10	36	17	27	33	43	27	42. 6	no
11	36	17	27	33	45	31	44. 8	no
12	36	17	27	33	45	27	46. 3	no

$$\text{Improvement} = \frac{39.0 - 36.7}{39.0} = 5.9\ \%$$

Note: The starting signal is No. 6 and the order of removal from the remaining group is 1, 2, 3, 4, and 5. The algorithm has been stopped at the end of one complete iteration.

one of them, we should hold fixed all the offsets on one side of S_j and vary together the offsets of S_j and all the signals on the other side. This procedure can be started at one end of the artery and carried through to the other. At the first step, all offsets but the first are changed together; at the second, all but the first two; and so on, with the group being changed shrinking by one at each step. We still call the process univar since, in effect, a single relative change dictates all the offsets.

The same idea can be extended to networks, but is not so clear there. A starting signal can be defined and the others put in a group with each signal assigned an order of removal. At each stage of univar the relative offset of all those in the shrinking group is varied with respect to the next. However, in the network case, there will often be more than one adjacent pair whose relative offset is being changed. Therefore, some of the intended effect is lost. Nevertheless, if the grouping is arranged so that one of the adjacent pairs is usually an important heavy flow street and the others are usually in less important places, the effect can still be quite strong.

The group change method has been applied to our network. One univar iteration has been performed and the results are given in Table 4. There is reasonably good improvement, again about 6 percent, although actually not quite as much as found by the one-signal-at-a-time method in its first iteration. However, the group change is expected to be at its best where arteries dominate the problem and such is not the case here.

CONCLUSIONS

A traffic simulation has been used to evaluate several methods of setting signals in a specific test problem. In addition, the simulation has been made an integral part of proposed search procedures for improving settings. The work suggests the following conclusions:

1. There are operationally significant differences among settings that might beforehand be expected to be good. For example, the settings for medium flow plotted in Figure 4 were chosen for their potential effectiveness, yet the range among them is about 20 percent in stops/vehicle, 50 percent in delay/vehicle, and 30 percent in our composite objective function.
2. The criterion adopted for evaluating system performance substantially affects the choice of setting and the operating results. Thus, Figure 4 shows that, at heavy flow, 100-second simswitch 1 would be best if stops were the only criterion, whereas maximal bandwidth would be best if delay were the only criterion.
3. It is difficult to predict what settings will be good without detailed examination of traffic movement. This is illustrated by the reversal of our expectations for simswitch and maximal bandwidth between high and low flows. A number of factors, such as turning percentages, flow levels, and pedestrian signals, may affect performance, whereas most mathematical optimization methods to date work with simplified models.
4. Settings with progressive timing seem more likely to be degraded in performance by turning vehicles than are systems with simultaneous switching. This reasonable result is suggested by runs with and without turns.
5. A promising approach to finding good settings is to develop likely ones by various methods, evaluate them by simulation, and then improve them by systematic procedures. Three methods of finding starting settings have been tried: maximal bandwidth progression, simswitch, and random search. Of these, maximal bandwidth has worked out fairly well in this test problem, but a single problem provides insufficient basis for generalization. Random search may be helpful if the simulation to be used is fast. A systematic improvement procedure using one-variable-at-a-time search is found effective in improving settings. Improvements in the case of this test problem have been on the order of 6-10 percent.

REFERENCES

1. Versace, John. Factor Analysis of Roadway and Accident Data. HRB Bull. 240, 1960, pp. 24-32.
2. Pennsylvania Turnpike Joint Safety Research Group. Accident Causation. Westinghouse Air Brake Co., Pittsburgh, 1954.
3. Traffic Control and Roadway Elements—Their Relationship to Highway Safety. The Automotive Safety Foundation, 1963.
4. Vey, Arnold H. Effect of Signalization on Motor Vehicle Accident Experience. Inst. of Traffic Eng. Proc., 1933, pp. 56-63.
5. Solomon, David. Traffic Signals and Accidents in Michigan. Public Roads, Vol. 30, No. 10, Oct. 1959, pp. 234-237.
6. Greenshields, Bruce D. Traffic Accidents and the Quality of Traffic Flow. HRB Bull. 208, 1959, pp. 1-15.
7. May, Adolf D. Friction Concept of Traffic Flow. HRB Proc., Vol. 38, 1959, pp. 493-510.
8. Casciato, L., and Cass, S. Progress and Experience in Toronto Traffic Control System. Conference on Traffic Surveillance, Simulation and Control, U. S. Bureau of Public Roads, Washington, 1964.
9. San Jose Traffic Control Project Progress Report. San Jose, Calif., May 1966.
10. Morgan, J. T., and Little, J. D. C. Synchronizing Traffic Signals for Maximal Bandwidth. Operations Research, Vol. 12, Nov. 1964, pp. 896-912.
11. Little, J. D. C. The Synchronization of Traffic Signals by Mixed Integer Linear Programming. Operations Research, Vol. 14, July 1966, pp. 568-594.
12. Gerlough, D. L., and Wagner, F. A. Simulation of Traffic in a Large Network of Signalized Intersections. Proc. Second Internat. Symp. on Theory of Traffic Flow, London, 1963.
13. Katz, J. H. Simulation of a Traffic Network. Communications of the ACM, Vol. 6, Aug. 1963, pp. 480-486.
14. Kell, J. H. Results of Simulation Studies as Related to Traffic Signal Operation. Presented at 33rd Annual Meeting, Inst. Traffic Eng., Toronto, 1963.
15. Blum, A. M. A General Purpose Digital Simulator and Examples of Its Application. Part III—Digital Simulation of Urban Traffic. IBM Systems Journal, Vol. 3, 1964, pp. 41-47.
16. Schwartz, Jesse G. An Urban Street Network Simulation Model. MIT Civil Eng. Dept. Rept., Cambridge, Mass., Nov. 1966.
17. Grace, Muriel J., and Potts, R. B. A Theory of the Diffusion of Traffic Platoons. Operations Research, Vol. 12, 1964, pp. 255-275.
18. Pacey, G. M. Progress of a Bunch of Vehicles Released From a Traffic Signal. Rept. No. RN/2665, Road Res. Lab., England, 1956.
19. Helly, W., and Baker, P. O. Accelerated Noise in a Congested Signalized Environment. Rept. R&D 65-2, Engineering Dept., Port of New York Authority, June 1965.
20. Webster, F. V. Traffic Signal Settings. Road Res. Tech. Paper No. 39, Her Majesty's Stationery Office, London, 1958.
21. Leon, A. Memoranda on Optimization Techniques. Sloan School of Management, MIT, 1966 (multilith).
22. Miller, S. B. The Solution of a Two-Dimensional Traffic Light Problem. Master's Thesis, MIT, 1966.

Median Barrier Photographic Study

JOSEPH V. GALATI, Bureau of Traffic Engineering,
Pennsylvania Department of Highways

A study has been performed to identify damages to and evaluate the effectiveness of the metal median barrier on the Schuylkill Expressway, Philadelphia, in relation to accident occurrence, volume and geometric design, using photography. The median barrier in Montgomery and Philadelphia Counties was photographed for approximately 20 miles using 35-mm strip film, which was then viewed on a dual projector console developed for the Pennsylvania Department of Highways.

The total number of various type median barrier damages detected in the 12-month study period was 1085. Though the traffic volume seemingly had little effect on the number of damages, the geometric design's influence was in evidence with interchange areas and curves showing considerably more impacts. Police accident reports were also studied both before and after the installation of the barrier to determine the effect it had on the number, type, and severity of accidents.

•THE OBJECTIVE of this study was to determine how well a median barrier functions as an integral highway element of vehicle control with respect to preventing median crossings, sustaining major and minor vehicular damages, and reducing both the frequency and severity of accidents.

The Schuylkill Expressway, on which this study was conducted, is the principal connection between the Pennsylvania Turnpike at the Valley Forge Interchange in the King of Prussia area and the downtown section of Philadelphia. The Expressway actually connects the turnpike interchange and the Walt Whitman Bridge crossing into New Jersey. The Expressway is approximately 20 miles long and consists of four-lane and six-lane sections divided by either a 4-ft wide raised median or a 10-ft wide flush median. It carries between 42, 000 and 130, 000 vehicles daily.

The Department of Highways erected 18. 4 miles of type 2 median guardrail during 1962. This steel beam guardrail is mounted "back-to-back" on 4-in. offset I-beam blocks which are attached to steel I-beam posts. The posts are spaced at 12-ft 6-in. intervals. The top edge of the rail is 24 in. above the pavement surface at the median and the lateral width of the rail is approximately 21 in. Approximately 11. 4 miles of barrier are located on the 4-ft median while 7. 0 miles are on 10-ft median.

A previous study was conducted to ascertain the "Effects of Guardrail in a Narrow Median Upon the Pennsylvania Driver" (Pennsylvania Dept. of Highways and U. S. Bureau of Public Roads, June 1964). To supplement that study it was felt that a more detailed analysis should be made of the damage incurred by the median barrier and if possible to determine its overall effectiveness.

In an effort to find out how often the median barrier was damaged it was photographed monthly and a projection film prepared. The film was viewed on a specially designed viewing console capable of projecting two films simultaneously on the console screen. Each monthly film was compared with the previous months' film and new damages were credited to the study month. Nine categories of damages were recorded and identified by station number of the highway and then coded for electronic data processing use.

Paper sponsored by Committee on Operational Effects of Geometrics and presented at the 46th Annual Meeting.

Figure 1. Film viewing console.

A one-year "before" and "after" median barrier installation accident study was also conducted. The results of the photographic portion of the study and the accident study were combined to determine the median barrier's effectiveness.

METHOD OF STUDY

In an effort to determine how often the median barrier was damaged, several approaches to the problem were considered. Due to the extreme hazard involved, several physical identification and notation procedures were abandoned. A new safe method was needed. Photography had been used for other type studies and it was proposed for this one. Since no one had prior experience in this area several methods had to be explored. As a result two possible types of photography were given consideration—strip film photography and 35-mm single-frame.

A pilot study photographing five miles of median rail was undertaken to decide which of these methods was better suited for this type of study. Much experimenting and comparison proved 35-mm strip film to be the more proficient method of photography. It assured more accuracy of detail and eliminated the need for splicing sections of film together.

An overall one-year comprehensive median barrier study was then begun. It was proposed to determine and evaluate through the use of photography the number of times the rail had vehicle contact, the severity of the contacts, and the relationship of contacts to volume and geometric design. Photographing of the median barrier took place monthly during the early hours of the morning with the use of floodlights. The barrier

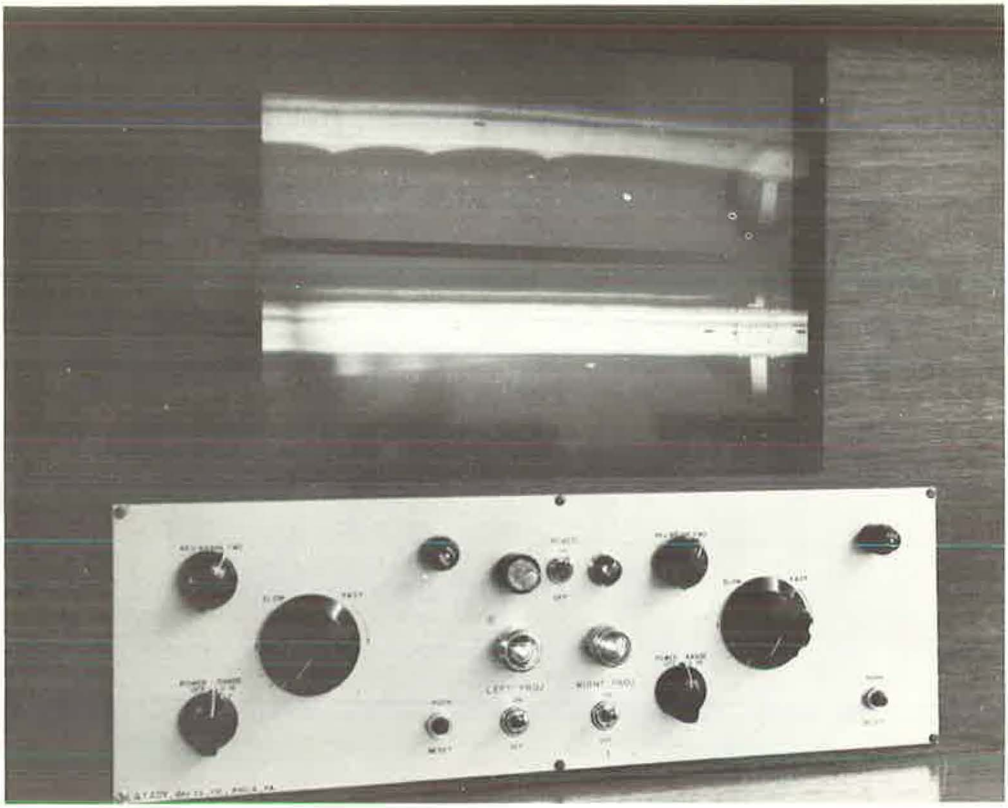


Figure 2. Console control panel and viewing screen.

was filmed from a moving vehicle averaging 30 to 35 mph in both eastbound and westbound directions. The film was processed and divided into four reels per month of equal ten-mile sections.

The Pennsylvania Department of Highways had devised a 35-mm strip film viewing console for the purpose of viewing monthly films (Figs. 1 and 2). The console's external appearance most nearly resembles the once-familiar player piano; that is, in the upper portion of the console, in the center, is a screen on which is viewed the moving median barrier. The "keyboard area" surface is used for recording collected data.

Basically the console can be divided into two sections, the base and the top. The base has four drawers, two on each side. The upper drawers house 35-mm strip film projectors. By the use of prisms and mirrors the images are reflected through the top portion of the console onto the viewing screen. The projector on the right produces its image on the upper half of the screen, the one on the left on the lower half. Since the projectors are housed within the drawers, cooling fans were provided to eject heat from the projectors. Focusing of the projectors and zooming to increase the size of the image on the screen can be accomplished by controls located on the outer face of the drawers.

Directly under the viewing screen is the console control panel. It provides for advance, stop, and reverse of each projector individually. The variable operational speed of each projector is also individually controlled. Power supply and projector protection fuses and on-off switches are also located in the panel.

The console design permits the department to obtain monthly summaries of median barrier damages by comparing one month's film with the previous month's film. This is done by loading both projectors with the same sections of filmed median barrier from succeeding months. The latest film is advanced until rail damage is detected and then stopped. The previous month's film is advanced to the same location. If the damage appears on both films it is known that the damage has been previously recorded. If the damage does not appear on the film of the prior month the damage is recorded and credited to the month of the latest film. To properly identify the same sections of median barrier on both films, sequential identification numbers, relating to highway station numbers, had been permanently applied to the barrier every 300 feet. The console is capable of projecting two films simultaneously across the screen by adjusting the variable speed controls.

MEDIAN BARRIER DAMAGES

In evaluating the effectiveness of the median barrier on the Schuylkill Expressway, it must be considered how often it is hit, and what the extent of the damage is.

The study area was photographed in both eastbound and westbound directions and the film examined for median barrier damage. The original filming, taken in May 1964, provided an inventory of all damages incurred by the metal median since its installation. Though it was common knowledge that the barrier had been struck many times not reflected in police accident reports, it was never known how many times it was actually hit. Varying types of damage totaling 4370 were found in the inventory, an average of 109 per mile.

Three classifications—minor, medium, and major—with nine more descriptive subdivisions, provided a means for establishing the severity of these damages. The nine progressively more severe classifications of damage were defined as follows:

1. Minor
   Scratch: slightest type of damage—very thin line of damage—not deep or wide—surface only.
   Scrape: wider than scratch and deeper into the rail's surface—a thick scratch.
   Dent: a slight indention in the rail's surface as if caused by a blunt instrument—no scratch or scrape involved.
2. Medium
   Scrape: similar in many ways to a minor scrape, but usually deeper and more severe, appears darker on film than minor scrape.
   Dent: indention of rail deeper than in the case of a minor dent—generally a series of deep dents closely grouped.
   Scrape and Dent: combination of denting and scraping of a severe nature, but not twisting the rail out of alignment.
3. Major
   Twisted Rail: rail hit with such impact that the alignment no longer exists—usually involves much scraping and extremely severe dents.
   Twisted Post: post supporting the guardrail has been bent from a vertical position and/or severed.
   Breakthrough: rail has been severed and laid open from top to bottom—most severe of all damage categories.

Of the 4370 recorded inventory impacts, 90 percent or 3996 fell into the minor category, 7 percent or 324 were medium, and the remaining 3 percent were major in nature. There were no breakthrough damages reported.

Because of an accumulation of dirt and wear on the median barrier when the original or inventory run was filmed it is probable that many of the medium scrapes were minimized to a minor type nature, thus accounting for an abnormal relationship between medium and minor. This conclusion was drawn as the result of physical investigation of a number of questionable areas.

The actual 12-month study period ran from June 1964 to May 1965, and does not include the inventory run in May 1964. All statistics are based on the 12-month study period only.

TABLE 1

TOTAL MONTHLY MARKINGS ON MEDIAN BARRIER ACCORDING TO SEVERITY INCLUDING INVENTORY RUN

Severity	1964							1965					Total
	May[a]	June	July	Aug.	Sept.	Oct.	Dec.	Jan.	Feb.	Mar.	Apr.	May	
Minor scratch	2142	77	17	9	5	15	15	0	7	4	15	20	2326
Minor scrape	1778	91	48	40	25	44	31	12	22	26	35	25	2177
Minor dent	76	4	1	1	0	0	5	1	1	0	0	0	89
Medium scrape	165	22	59	46	24	58	17	15	14	32	44	59	555
Medium dent	36	2	0	1	0	1	1	1	2	0	0	0	44
Medium scrape and dent	123	3	6	3	4	1	13	2	1	2	12	12	182
Major twisted rail	31	4	4	4	1	2	8	0	2	1	1	2	60
Major twisted post	19	0	0	1	1	0	1	0	0	0	0	0	22
Major breakthrough	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	4370	203	135	105	60	121	91	31	49	65	107	118	5455

[a] Original inventory run.

TABLE 2

TOTAL MONTHLY MARKINGS ON MEDIAN BARRIER ACCORDING TO SEVERITY, PHILADELPHIA COUNTY

Severity	1964						1965					Total
	June	July[a]	Aug.	Sept.	Oct.[b]	Dec.[b]	Jan.[c]	Feb.	Mar.	Apr.	May	
Minor scratch	38	15	6	3	10	14	0	3	2	13	11	115
Minor scrape	53	42	18	17	25	22	10	19	12	22	19	259
Minor dent	1	0	0	0	0	5	1	0	0	0	0	7
Medium scrape	3	45	29	8	39	9	11	8	22	36	47	257
Medium dent	0	0	0	0	1	1	1	1	0	0	0	4
Medium scrape and dent	2	2	2	2	0	7	1	0	0	11	10	37
Major twisted rail	0	2	1	1	1	4	0	1	1	0	2	13
Major twisted post	0	0	0	1	0	0	0	0	0	0	0	1
Major breakthrough	0	0	0	0	0	0	0	0	0	0	0	0
Total	97	106	56	32	76	62	24	32	37	82	89	693

[a] July film was underexposed.
[b] No film taken in November.
[c] Total for January is low due to deposits of ice and snow on the median barrier.

Because June 1964 was the first actual month of the study following the inventory, it is presumed that some damages were missed in viewing the inventory run and were consequently picked up in the June viewing of film, resulting in an abnormally high total (Table 1). In January 1965, a heavy accumulation of ice and snow on the median barrier made most damages undetectable, resulting in an abnormal low.

An analysis of both directions of the Philadelphia County study area from City Line to the Walt Whitman Bridge (approximately 7. 5 miles) revealed 693 total damages to the median barrier, or an average of 46 per mile for both sides combined. The severity percentages for this area were: minor 55 percent (381 impacts), medium 43 percent (298 impacts), and major 2 percent (14 impacts). Examining the subdivisions, we find minor scrapes and medium scrapes equally responsible for a total of 516 (76 percent) of the Philadelphia area damages. There were 13 major damages but no breakthroughs (Table 2). The Philadelphia study area carries a volume up to 130, 000 ADT.

The King of Prussia to City Line study area (approximately 12. 47 miles) in Montgomery County has an ADT volume of 42, 000. In this study area 392 damages were found, an average of 15. 5 per mile. The severity percentages for Montgomery County were: minor 55 percent (215 impacts), medium 40. 5 percent (159 impacts), and major 4. 5 percent (18 impacts). The minor scrape and medium scrape subdivisions account for 273 damages or 70 percent of the total for Montgomery County (Table 3).

A study of damages by locations revealed some clustering. Four to seven median barrier damages within 200 ft is referred to as cluster type No. 1; cluster type No. 2 is nine or ten median barrier damages within 100 ft. All No. 1 type damage clusters were located at interchange areas involving off and/or on ramps (Fig. 3). Two type No. 2 clusters developed. At station 322 + 00 eastbound, on a curve, nine medium scrape damages were found, and at station 398 + 00 westbound, on a tangent section, ten damages were located varying from a minor scratch to a twisted rail.

Two widths of median were included in the Montgomery County study, 7. 5 miles of 10-ft wide grass median and 4. 9 miles of 4-ft concrete. In the 10-ft wide sections

TABLE 3

TOTAL MONTHLY MARKINGS ON MEDIAN BARRIER ACCORDING TO SEVERITY, MONTGOMERY COUNTY

Severity	1964						1965					Total
	June	July[a]	Aug.	Sept.	Oct.[b]	Dec.[b]	Jan.[c]	Feb.	Mar.	Apr.	May	
Minor scratch	39	2	3	2	5	1	0	4	2	2	9	69
Minor scrape	38	6	22	8	19	9	2	3	14	13	6	140
Minor dent	3	1	1	0	0	0	0	1	0	0	0	6
Medium scrape	19	14	17	16	19	8	4	6	10	8	12	133
Medium dent	2	0	1	0	0	0	0	1	0	0	0	4
Medium scrape and dent	1	4	1	2	1	6	1	1	2	1	2	22
Major twisted rail	4	2	3	0	1	4	0	1	0	1	0	16
Major twisted post	0	0	1	0	0	1	0	0	0	0	0	2
Major breakthough	0	0	0	0	0	0	0	0	0	0	0	0
Total	106	29	49	28	45	29	7	17	28	25	29	392

[a] July film was underexposed.
[b] No film taken in November.
[c] Total for January is low due to deposits of ice and snow on the median barrier.

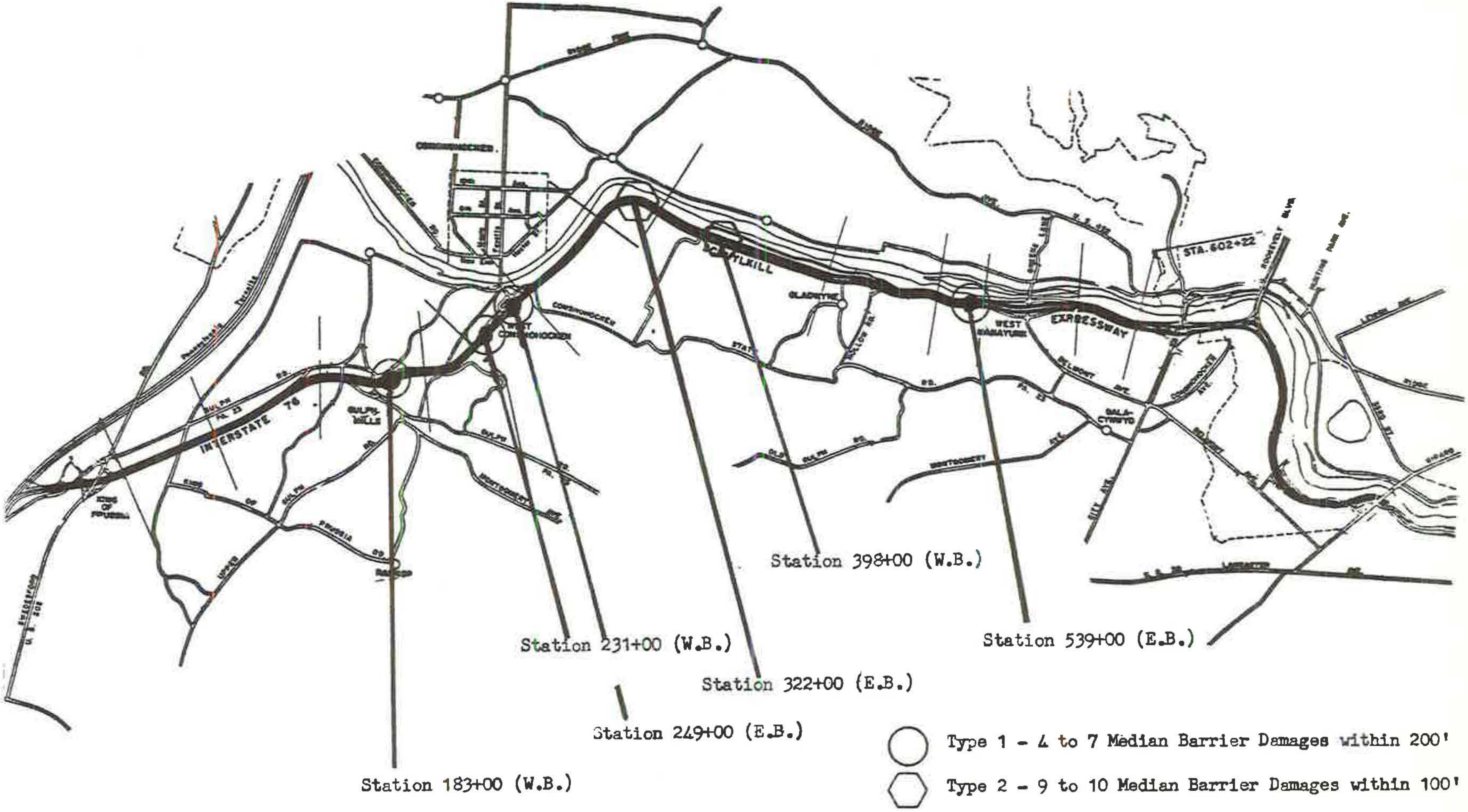


Figure 3. Location of barrier damage clusters.

TABLE 4

ACCIDENT SEVERITY

Category	1960-61	Projected[a] 1964-65	1964-65[b]	Percentage of Abnormal Increase or Decrease
Average daily volume	28, 533	—	42, 515	—
Total number of accidents[b]	153	227	265	+24
Percentage of accident increase	—	49	73	+24
Number of fatal accidents	4	6	5	—
Number of injury accidents	48	72	81	+20
Number of property damage accidents	101	150	179	+28
Total number killed	7	10	6	—
Total number injured	78	117	122	+ 7

[a] Totals in this column represent a projected increase of 49 percent over the original totals for 1960-61, based on the 49 percent increase in the average daily volume over the four-year period.

[b] As reported by State Police, Montgomery County.

TABLE 5

MEDIAN BARRIER ACCIDENTS

Category	1960-61	Projected[a] 1964-65	1964-65	Percentage of Abnormal Increase or Decrease
Accidents involving median[b]	20	30	52	+111
Crossover accidents	(20)	(30)	(0)	—
Median barrier accidents	(—)	(—)	(52)	—
Fatal accidents involving median	3	4	0	—
Injury accidents involving median	7	10	19	+122
Property damage accidents involving median	10	15	33	+181
Number killed in median accidents	6	9	0	—
Number injured in median accidents	16	24	25	+ 7

[a] Totals in this column represent a projected increase of 49 percent over the original totals for 1960-61, based on the 49 percent increase in the average daily volume over the four-year period.

[b] As reported by State Police, Montgomery County.

TABLE 6

COLLISION TYPES AND MEDIAN INVOLVEMENT

Collision Type	1960-61	Projected[a] 1964-65	Actual 1964-65	Median Involved[b]	
				1960-61	1964-65
Head on	8	12	1	7	0
Rear end	90	135	128	2	7
Angle	14	21	11	8	0
Sideswipe	11	16	25	0	3
Hit fixed object	21	31	93	3	42
Other	9	12	7	0	0
Total	153	227	265	20	52

[a] 1960-61 Totals projected 49 percent based on 49 percent increase in traffic volume.

[b] 1960-61 Totals include median crossings, 1964-65 totals include hitting median barrier.

TABLE 7

ORDER OF IMPACT ACCORDING TO FIXED OBJECT TYPE[a]

Fixed Object Type	First Thing Hit	Second Thing Hit	Third Thing Hit	Total
Median barrier	39	11	2	52
Guardrail	18	1	0	19
Bridge abutment	8	1	0	9
Embankment	19	4	0	23
Curb	5	1	0	6
Temporary control device	1	0	0	1
Other	2	0	0	2
Unknown	1	2	0	3
Total	93	20	2	115

[a] Applies only to 1964-65 data, i.e., after installation of the median barrier.

there were a total of 213 film-recorded damages for an average of 15 damages per mile, including both sides of the median. In the 4-ft wide sections there were a total of 174 recorded damages for an average of 18 per mile.

Percentagewise, there is 40 percent of 4-ft wide median and 60 percent of 10-ft wide median. Of the total 265 State Police-investigated accidents during the study period, 92 (43 percent) occurred in the 4-ft section. Of the 52 State Police-investigated accidents in which the median was involved, 22 (43 percent) occurred in the 4-ft section.

The 4-ft concrete median, therefore, experiences more activity than the 10-ft grass median. Though it contains 40 percent of the total mileage, it experiences 4.5 percent more damages per mile than the 10-ft median and 3 percent more police-investigated accidents than its proportional mileage.

ACCIDENTS

In 1964 the Pennsylvania Department of Highways published the technical report "Effects of Guard Rail in a Narrow Median Upon the Pennsylvania Driver." Part II of that report was concerned with a "before" and "after" accident study related to the installation of a back-to-back beam-type median barrier. The accident study was based on State Police and City of Philadelphia Police accident reports. It was concluded using police data that in a one-year period before and after installation of the median barrier accident frequencies increased 73 percent and 38 percent in each of two sections studied with a 10 percent increase in volume.

To minimize the effect which the installation of the median barrier would have on an immediate "after" study as reported in 1964, State Police accident records were again analyzed for two comparable one-year periods. The "before" period (prior to installation of the median barrier) was June 1960 to May 1961; the "after" period was June 1964 to May 1965. The "after" period begins approximately two years after the completion of the installation of the median barrier—sufficient time for the motorist to become familiar with and accustomed to the new physical conditions. The "after" accident study period is compatible with the photographic phase of this report.

The following analysis is based on State Police-investigated accidents for the Montgomery County study area only. There was a total 153 accidents in the "before" period and 265 in the "after" period, a percentage increase of 73. In the "before" period traffic volumes averaged 28,533 per day, in the "after" period 42,515, an increase of 49 percent for the four-year period.

Assuming that frequency of accidents is linearly affected by volume for a constant roadway, the "before" accident total should be adjusted 49 percent from a total of 153 to 227. The difference between 227 and 265 accidents reflects a 24 percent abnormal increase of accidents. It is acknowledged that accident frequency is probably more than linearly related to vehicle mileage; however, no mathematical relationship is known to allow a more exact calculation of "abnormal" accident frequency increase.

Tables 4 and 5 present "before" and "after" accident occurrences with respect to the number and severity of all accidents and of those accidents which involve the median only. As Table 4 indicates, there was an "abnormal" total accident increase of 24 percent. This is the difference between 73 percent actual increase in the number of accidents and the projected total increase of 49 percent. There was a reduction from the projected total for fatal accidents. The increase in property damage accidents is the significant factor in this table. The difference in the number of persons killed is not significant.

Table 5 is concerned with State Police-reported accidents involving the median barrier. Crossover accidents did not occur during the "after" period of this study, shown in the 1964-65 column as (0). Median barrier accidents could not have occurred in the "before" period and are reported in the 1960-61 and projected columns as (—).

In the 1960-61 study 20 crossover accidents occurred. Three were fatal accidents, with six persons killed; seven were injury accidents, with 16 persons injured; ten were property damage accidents. The 52 reported median barrier accidents indicate an abnormal increase of 111 percent over the projected 1964-65 figure of 30.

Fatal accidents involving the median have been eliminated during the study period. Injury accidents had an abnormal increase of 122 percent and property damage accidents an abnormal increase of 181 percent.

Table 6 summarizes the type of accidents. The collision type was determined not by the severity of the various types that could be included in one particular accident but by the first event regardless of its severity. In the category of sideswipe accidents the table indicates that in 1960-61 there were 11 such accidents and in 1964-65 a total of 25. In the "before" study the median was not subsequently involved in the 11 accidents. In the "after" study the median was involved three times after the event of the sideswipe. This is not to conclude that other sideswipes did not occur as part of other accidents. For instance, the category of "hit fixed object" could include accidents consisting of first hitting the median barrier, then moving to the right and sideswiping a vehicle in the other lane.

Table 6 indicates again the elimination of crossover head-on accidents in the "after" study. The other significant category is "hit fixed object." The "before" period had 21 such accidents and involved the median only three times. The 49 percent projected increase to 31 such accidents was exceeded by over 290 percent and the median was involved 42 times, a clear indication that the median is an accident factor to be seriously considered.

The hit-object accidents are further analyzed in Table 7 for the "after" study only. It indicates that, in the 52 police-reported accidents involving the median, 39 (75 percent) hit the median barrier first, the others as a result of some other type accident. Of all things hit first the median constituted 42 percent.

MEDIAN BARRIER DAMAGES AND ACCIDENTS

A question asked many times but as yet unanswerable is, "How many vehicles cross the median which does not have a physical barrier and are not involved in accidents since they were able to regain control, turn around, and proceed on their trip?" No attempt is made here to answer this question based on the data collected. The type of data collected does, however, provide some insights.

In the "before" accident study there were a total of 20 reported crossover accidents, in the "after" study none. Had the median barrier not been installed and the 20 crossover accidents increased by 49 percent (the increase of volume) perhaps 30 crossover-type police-investigated accidents would have taken place. This figure of 30 is the projected number of State Police-investigated crossover-type accidents. It does not give an insight into how many could have crossed and returned safely.

An analysis of all State Police-reported accidents for the "after" study indicates that of the 265 total, 52 involved the median barrier. These 52 accident reports were matched with the damages recorded on the photographic study. They comprised 18 minor, 32 medium, and 2 major type damages.

Next the type of accidents, speeds, location of damages to the rail, size of damages, etc., were analyzed. It was determined that, of the 18 minor barrier damages reported by State Police investigations, 13 (83 percent) would have at the minimum encroached onto the median and perhaps crossed over. The other 5 were of such a nature that had the median barrier not been installed the vehicle would have continued safely along its way. Of the 32 medium barrier damage accidents, 27 (84 percent) would have encroached or crossed the median, and of the major barrier damage accidents 100 percent would have crossed.

In the Montgomery County study area there were a total of 392 median barrier damages recorded by the photography process. Of these 215 were of the minor type, 159 were medium and 18 were major. Had all these recorded damages been investigated by police a determination of each could be made as to whether or not the vehicle would have crossed the median. This not being the case, the next logical approach was to apply the percentages of those accidents which were investigated by the police. Thus, 83 percent applied to the 215 recorded minor barrier damages would be 178; 84 percent applied to the 159 recorded medium barrier damages would be 134; and 100 percent applied to the 18 recorded major barrier damages would be 18.

This totals 330, which represents the number of film-recorded barrier damages which could have resulted in vehicles encroaching or crossing the median had the median barrier not been in existence. Since the projected 1964-65 crossovers totaled 30, it could be assumed that 300 vehicles suffered either initial or additional damages as a result of the installation of the median barrier.

CONCLUSIONS

The total number of various types of median barrier damage detected in the 12-month study period was 1085. Damages of a scraping nature represented 70 percent of the total in the study period. There were no breakthrough type damages recorded. Though the traffic volume seemingly had little effect on the number of damages, the geometric design's influence was in evidence, with interchange areas and curves showing considerably more impacts.

State Police accident reports for the 12.47-mile Montgomery County section were studied both before and after the installation of the barrier to determine the effect it had on the number, type, and severity of accidents. The period before installation totaled 153 police-investigated accidents compared with 265 after the barrier was installed, representing an abnormal growth over volume of 24 percent. Of the 265 police-investigated accidents, 52 resulted in damage to the median barrier. In the one-year "before" accident study there were 20 police-investigated crossover accidents. No crossovers were reported in the "after" study by the police.

For this same 12.47-mile area there were 392 photographically recorded rail damages. A detailed analysis of the 52 police-investigated reports mentioning damages to the median barrier indicated that, of the total 392 damages, approximately 330 represent vehicles which could have encroached on the median or crossed, had the barrier not been in existence. Of these 330 damages, it could reasonably be assumed that 300 vehicles suffered either initial or additional damage as a result of the installation of the median barrier. It is possible that many of these 300 vehicles would not have been involved in any accident had the median barrier not been installed. These in effect represent vehicles that cross medians (without barriers) and do not become involved in accidents, but regain control and continue on their trip.

The method of study used in this project is being considered by the Pennsylvania Department of Highways as a new research tool. It has the advantages of making collected field data permanent and capable of future review. The method also eliminates the hazards involved if personnel had to be placed in the field, on the highway, to collect the same data. It converts expensive long hours of field time to standard office hours.

Adjustments which have to be made during the period of a study, changes in procedures, etc., can be handled by standard office routine. The requirements for special equipment are also reduced to standard office needs.

It is anticipated that in the future more extensive median barrier studies will be undertaken on the type studied here and also on other type barriers. It is the author's conclusion that even though considerable material concerning median barrier damages has been reported herein, the method of study is of equal if not of more significance.

ACKNOWLEDGMENTS

This study has been sponsored by the U. S. Bureau of Public Roads and performed by the Division of Research and Studies, Traffic Engineering Bureau, Pennsylvania Department of Highways.

Robert R. Coleman, Assistant Director of the Bureau of Traffic, was instrumental in conceiving the method of study used in the report and the design of the twin-projector strip film viewing console. Latady Development Company of Philadelphia, the contractor, engineered the construction of the console and perfected its operation. Latady Development Company also filmed the median barrier monthly and processed the study film.

Robert H. MacGinnes, Jr., technician in the Division of Research and Studies, deserves special mention for the laborious task of viewing film representing over 500 miles of median barrier to select and catalog monthly damages as they appeared on the film. He also analyzed and categorized the State Police accident reports for both the "before" and "after" periods of the study.

Sign Backgrounds and Angular Position

DOUGLAS R. HANSON and HENRY L. WOLTMAN, 3M Company

•INCREASING traffic volumes and higher operating speeds combined with the increased frequency of traffic signs place utmost importance on effective signs and signing systems to guide and control traffic safely and expeditiously. Valuable research work has been done in the area of effective signing, particularly on sign legibility, by Forbes, Moskowitz, Solomon, Holmes, Lauer, and others; however, signing literature suggests that further efforts are necessary concerning sign effectiveness, specifically on factors which attract a motorist's attention to the sign. This paper considers sign target value and angular position, two major factors in compelling driver attention (1).

TARGET VALUE

Target value is the ability of a sign to be visible against its background and provide early recognition and discrimination of the sign type which, in turn, prepares the driver for the potential message moments before actual reading of the legend. Major factors affecting the target value of a sign are its color and brightness, producing whatever measure of contrast the natural environmental background permits.

The visual factors of color and contrast are relatively well understood. As shown by Hanson and Dickson (2), the more contrast a sign has with its background, the greater will be the distance for its discrimination and recognition. Forbes (3) found that a given sign color possessed a range of effectiveness depending upon the prevailing background. It is apparent that backgrounds are very influential in the consideration of a proper sign; and, conversely, if strengths or weaknesses of a particular hue or saturation are discovered, they will most likely be closely related to the nature of the background. Both background and sign position are also shown to be dependent on terrain and type of roadway. To maximize sign effectiveness for an entire system on a basis of utilizing a single relatively uniform color, careful consideration of all potential backgrounds should be made. The diversity of backgrounds with which a sign must compete is very broad. There is, however, virtually no published information on the nature or frequency of the various existing backgrounds.

ANGULAR POSITION

Although target value is greatly influenced by background, it is somewhat dependent on the sign's position with respect to the driver's central point of fixation.

Matson (1, pp. 308-309) points out: "The accuracy of identification of traffic signs increases as the angle between the axis of vision and a line drawn from the traffic sign to the motorist's eye decreases." This is supported by Kingslake (4) reporting on research findings of Werheim shown in Figure 1. The acuity of peripheral vision decreases rapidly as angular displacement relative to the fixation point increases. According to Chapanis (5), this is due principally to a heavy concentration of visual perceptors in the immediate vicinity of the fovea. For optimum attention and identification, Matson (1, p. 309) suggests that a sign should fall within a visual cone of 10 to 12 deg on the horizontal axis and 5 to 8 deg on the vertical axis, throughout the intended range of sign effectiveness. This would probably encompass a distance extending from a point just prior to the sign's message becoming legible to approximately 300 ft from a sign. Greenshields (6) states that 5 deg to the left or right is ideal for sign placement but that practical considerations may force a wider visual field and suggests a value of 10 deg to the left or right as maximum angular displacement.

Paper sponsored by Committee on Traffic Control Devices.

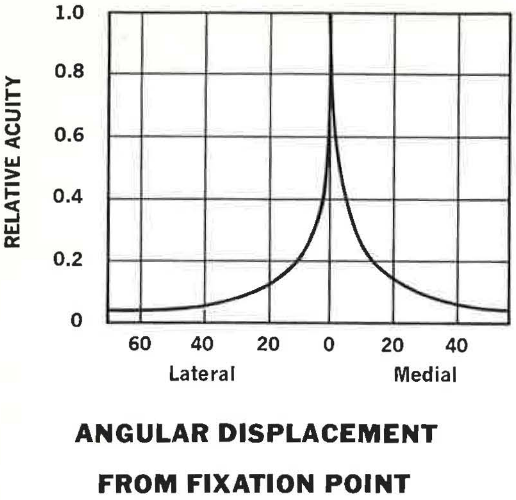


Figure 1. Peripheral visual acuity.

Figure 2. Transparent plastic shield in place with sign positions and driver's visual axis marked.

FIELD STUDY

The field study consisted of recording a sample of sign backgrounds on Interstate highways and other high-quality facilities with simultaneous recording of the angular position relative to the driver's visual axis, including a comparison of these findings with Matson's criteria above. Additional information obtained included sign placement, either overhead or shoulder-mounted; type of facility, whether at-grade, elevated or depressed; and environment, whether rural, suburban, or business. The rural environment possesses little, if any, housing or commercial activity, while suburban is principally residential with occasional abutting commercial property. The business classification has heavy and frequent commercial facilities immediately adjacent to the roadway.

To obtain angular sign position, a screen of rigid transparent plastic was secured in a vertical position between the steering wheel and windshield. As a sign was approached, the driver would mark its location on the transparent screen when it first became legible. The driver's visual axis was located by placing a cross on the screen at a point of infinite distance on the lane ahead. Figure 2 shows the transparent shield in position with sign positions and the visual axis marked.

All data pertaining to both sign backgrounds and angular position were taken at a distance where the sign copy first became legible. This is the earliest common reference for all signs within the range where target value is influential. The driver's vision was corrected to 20/20. The driver marked the sign position while an observer simultaneously recorded the background data.

The sample selection was based principally on consideration of the types of terrain and environmental areas through which Interstate-type facilities would pass. Information was obtained in several major metropolitan areas, in gently rolling as well as flat agricultural terrain, in very hilly regions in the Sierra Nevada mountains, and in the Mojave desert. This included 1560 miles of representative freeway facilities in California, Pennsylvania, New York, Illinois, Minnesota, Wisconsin, and Nevada comprising 4054 destination and distance signs.

RESULTS AND ANALYSIS

Background Study

The information obtained for sign background was categorized by six types of terrain, as follows:

TABLE 1

BACKGROUNDS OF SIGNS—OVERALL TOTALS

Background	Number of Signs and Percent of Total					
	Overhead		Shoulder		Combined	
	No.	%	No.	%	No.	%
Sky	603	35.8	174	7.3	777	19.1
Trees						
Dark green	180	10.7	752	31.8	932	23.1
Bright green	15	0.9	106	4.5	121	2.9
Grass						
Tan	23	1.4	152	6.4	175	4.3
Green	11	0.7	91	3.8	102	2.5
Building	123	7.3	98	4.1	221	5.4
Advertising signs	38	2.3	119	5.0	157	3.9
Road	9	0.5	74	3.1	83	2.0
Bridge	333	19.8	295	12.4	628	15.6
Sand	2	0.1	46	1.9	48	1.2
Dark hill	77	4.6	154	6.5	231	5.7
Sky and building	29	1.7	6	0.3	35	0.9
Sky and bridge	109	6.6	56	2.4	165	4.1
Sky and natural						
Dark	127	7.5	171	7.2	298	7.3
Light tan	2	0.1	4	0.2	6	0.1
Bright green	—	—	27	1.1	27	0.7
Red rock	—	—	8	0.3	8	0.2
Grey rock	—	—	40	1.7	40	1.0
Totals	1681	100	2373	100	4054	100

1. Metropolitan—includes suburban and business areas of Chicago, Los Angeles, San Francisco, Minneapolis, and St. Paul.
2. Gently Rolling—principally rural with an occasional town; terrain is gently rolling and used for agricultural purposes.
3. Mountainous—exclusively mountainous, mostly rural, with an occasional town.
4. Flat, Highly Populated, Agricultural—a combination of rural, suburban, and business areas with a fairly high population density; abutting land is quite flat and is used mainly for agricultural purposes. Such terrain is typical of much of the more densely populated areas of the United States.
5. Very Hilly—basically rural with occasional towns.
6. Desert—flat desert country with distant hills and mountains.

Background data for overhead and shoulder-mounted signs were summarized independently for each of the six categories considered. A combined total by background was also obtained for each category. These values were then combined to provide an overall total for the study.

Backgrounds were grouped into 16 different types. These are shown in Table 1, which is the overall sign background summary for the study.

Several of the background types need further definition. The dark tree background is a deep olive drab color corresponding roughly to U. S. Army Engineers Standard Camouflage Color No. 9 (7). The bright tree background is a light, bright-colored green observed occasionally on brush. The building background refers principally to large office buildings of intermediate greys and browns with only occasional buildings of a residential nature. The road category refers to instances where road curvature or a ramp caused the sign to be seen against the roadway surface. Bridges were generally a dark brown color, particularly in metropolitan areas; however, some fairly new bridges were tan. Substantial portions of the bridge structures were often in the shade resulting in a hue darker than expected. The dark hill background occurred when the hill was at some distance from the sign. At great distance hills became nearly achromatic, appearing to be a combination of deep dark green and brown, almost black. At times the sign would be seen partly against the sky and partly against some other background.

The overall totals in Table 1 show that the dark tree background was encountered most frequently—23 percent of the time—followed by a sky background, which was observed 19 percent of the time. Inspection of the overhead-shoulder breakdown shows that for shoulder-mounted signs the dark tree background was predominant—51. 8 percent. The incidence of bridge backgrounds was higher than anticipated—15. 6 percent of all sign backgrounds. The frequency of advertising sign backgrounds was a surprisingly low 3. 9 percent of the total.

It is possible to group the background types further into sky, dark, and all other background categories which allow comparison with Forbes' (3) preliminary findings regarding sign effectiveness. For the dark backgrounds it is necessary to combine the dark tree and the dark hill backgrounds, one-half the bridge backgrounds, one-half the building backgrounds, and one-half the sky plus other backgrounds. This amounts to approximately 44 percent of the total sign backgrounds. A sky background existed 19 percent of the time and all other types of backgrounds combined occurred 37 percent

TABLE 2

BACKGROUNDS OF SIGNS—METROPOLITAN AREA

Background	Number of Signs and Percent of Total					
	Overhead		Shoulder		Combined	
	No.	%	No.	%	No.	%
Sky	318	34. 3	40	9. 6	358	26. 7
Trees						
Dark green	104	11. 2	117	28. 2	221	16. 5
Bright green	8	0. 9	26	6. 3	34	2. 5
Grass						
Tan	6	0. 7	18	4. 3	24	1. 8
Green	—	—	18	4. 3	18	1. 3
Building	97	10. 5	52	12. 5	149	11. 1
Advertising signs	13	1. 4	12	2. 9	25	1. 9
Road	4	0. 4	14	3. 4	18	1. 3
Bridge	197	21. 2	66	15. 9	263	19. 6
Sand	—	—	—	—	—	—
Dark hill	5	0. 5	6	1. 4	11	0. 8
Sky and building	29	3. 1	4	1. 0	33	2. 5
Sky and bridge	84	9. 1	9	2. 1	93	6. 9
Sky and natural						
Dark	62	6. 7	34	8. 1	96	7. 1
Light tan	—	—	—	—	—	—
Bright green	—	—	—	—	—	—
Red rock	—	—	—	—	—	—
Grey rock	—	—	—	—	—	—
Totals	927	100	416	100	1343	100

TABLE 3

BACKGROUNDS OF SIGNS—GENTLY ROLLING AREA

Background	Number of Signs and Percent Total					
	Overhead		Shoulder		Combined	
	No.	%	No.	%	No.	%
Sky	37	33. 9	52	15. 5	89	20. 1
Trees						
Dark green	19	17. 4	123	36. 8	142	32. 2
Bright green	—	—	1	0. 3	1	0. 2
Grass						
Tan	—	—	9	2. 7	9	2. 0
Green	—	—	40	12. 0	40	9. 0
Building	2	1. 8	6	1. 8	8	1. 9
Advertising signs	4	3. 7	1	0. 3	5	1. 1
Road	—	—	1	0. 3	1	0. 2
Bridge	17	15. 6	27	8. 1	44	9. 9
Sand	—	—	—	—	—	—
Dark hill	—	—	—	—	—	—
Sky and building	—	—	—	—	—	—
Sky and bridge	6	5. 6	12	3. 6	18	4. 1
Sky and natural						
Dark	24	22. 0	38	11. 4	62	14. 0
Light tan	—	—	1	0. 3	1	0. 2
Bright green	—	—	23	6. 9	23	5. 2
Red rock	—	—	—	—	—	—
Grey rock	—	—	—	—	—	—
Totals	109	100	334	100	443	100

of the time. The predominance of dark backgrounds in the natural surround was unanticipated, particularly for the overhead situation. Although Forbes' investigation is still in progress, early findings reported that a dark green sign was seen "first and best" against a sky background and that a highly saturated bright green was seen "first and best" against a dark hill background. Studies are in process to evaluate other pertinent factors; however, the results reported are not unexpected since contrast with the background should be an influential factor.

Analysis of the type and frequency of various backgrounds by each of the six basic areas studied provides further knowledge of existing sign background conditions. The summary for the metropolitan area (Table 2) shows a high incidence of sky backgrounds (26. 7 percent) and bridge backgrounds (19. 6 percent), particularly for overhead installations. The ratio of overhead to shoulder installations was slightly greater than 2 to 1. The percentage of dark tree backgrounds was fairly high—16. 5 percent of the total. Table 3 summarizes the backgrounds of signs in the gently rolling area. Dark tree backgrounds are predominant, occurring 32. 2 percent of the time. As expected, the desert area totals (Table 4) show that sand backgrounds were most common. The terrain in the desert was very flat and the freeway traveled was overpassed by crossing roads which resulted in sand embankment backgrounds.

Sign backgrounds for the flat, highly populated, agricultural area are shown in Table 5. Background percentages for this area parallel quite closely those for the overall study totals. Because the terrain is quite flat, the incidence of overhead signs with a sky background is high (41. 7 percent). However, in the combined overhead and shoulder totals, dark tree backgrounds are predominant. In both the very hilly area (Table 6) and the mountainous area (Table 7) the frequency of sky backgrounds was extremely low, particularly in the mountainous area where only 1 sign out of 337 was seen against the sky. In the mountains, a dark tree background occurred 44 percent of the time. In the hilly area, a tan grass background was encountered at the time the study was conducted. In other climates similar backgrounds would obviously be green.

The data were summarized by facility type to determine what effect this variable would have on sign background. Table 8 indicates that 81 percent of the signs were installed on at-grade facilities; 42 percent of the sign backgrounds for depressed facilities possess either bridge or combined bridge and sky background. On at-grade facilities, dark tree or dark hill backgrounds occur 31 percent of the time.

A further analysis of the background information was made, summarizing the data by roadway environment (Table 9). A majority of the total signs, 57 percent were in either a suburban or business environment. In general, the majority of sign backgrounds for both rural and suburban areas consists of trees, whereas the majority of sign backgrounds in the business areas consists of bridge backgrounds.

During the field stduy, information regarding the average number of signs per mile was obtained. For rural areas the average was 1. 4 signs per mile, and for metropolitan areas, 5. 3. The number of signs per mile averaged 2. 6 for the entire study.

Seasonal Variation

All of the data for this study were collected during the summer months. Obviously the season of the year would affect sign backgrounds to a certain degree, particularly in the northern latitudes where seasonal color changes are relatively great. For an accurate determination of the effect of seasonal change, each locale would require independent consideration.

In areas having predominantly deciduous trees, the turning leaves would create a multicolored effect for a brief period during the fall and then as the trees shed their leaves, backgrounds become almost black in color until spring. Little seasonal change would occur for conifers. The incidence of grass sign backgrounds was not high; therefore, seasonal changes would have little overall effect. Snow in the mountainous areas would be expected to have a greater effect on sign backgrounds because of the high frequency of signs being viewed against natural backgrounds. In the metropolitan areas signs had either a sky background, a bridge background, a building background, or some combination of these 66. 8 percent of the time. Because of this, seasonal variations would seem to have little effect in metropolitan areas.

During the field study it was noted that the motorist is often confronted with numerous signs at one time. Although unrelated to the objectives of this study, a sample was taken of the number of signs which were in very close proximity. Percentages are not available, but it was frequently noted that five and six signs required concurrent attention in metropolitan areas. In rural areas, longitudinal spacing of signs prevented this situation.

Angular Position

Distribution patterns obtained from the field study of angular sign position relative to the motorist's visual axis are shown in Figures 3 through 6. Median points for each distribution are indicated, total angular span is shown, and the 8-deg vertical and 12-deg horizontal optimum angular span suggested by Matson (1, p. 309) is defined. Table 10 lists the percentage of signs which fall outside the optimum angular range by type of installation for each of the four terrain types. Inspection of the distributions and Table 10 indicates that, with the exception of flat terrain, a significant number of signs have greater than optimum angular displacement. This situation is most severe for shoulder-mounted signs in the mountainous area (Fig. 6) where 53 percent are outside the optimum range. This is caused by the winding roads and deep cut banks which, in many cases, hide a sign until the motorist is very close and angular displacement great. All median points are, however, well within the optimum angular range. As would be expected, the median point for overhead signs was above and to the left of shoulder-mounted signs in all cases.

TABLE 4

BACKGROUNDS OF SIGNS—DESERT AREA

Background	Number of Signs and Percent of Total					
	Overhead		Shoulder		Combined	
	No.	%	No.	%	No.	%
Sky	8	27.6	11	10.2	19	13.9
Trees						
Dark green	—	—	5	4.6	5	3.6
Bright green	—	—	—	—	—	—
Grass						
Tan	—	—	9	8.3	9	6.6
Green	—	—	4	3.7	4	2.9
Building	2	6.9	2	2.0	4	2.9
Advertising signs	—	—	4	3.7	4	2.9
Road	—	—	6	5.6	6	4.4
Bridge	6	20.7	6	5.6	12	8.8
Sand	2	6.9	28	25.9	30	21.9
Dark hill	2	6.9	23	21.3	25	18.2
Sky and building	4	13.8	2	1.8	2	1.5
Sky and bridge	—	—	—	—	4	2.9
Sky and natural						
Dark	3	10.3	7	6.4	10	7.3
Light tan	2	6.9	1	0.9	3	2.2
Bright green	—	—	—	—	—	—
Red rock	—	—	—	—	—	—
Grey rock	—	—	—	—	—	—
Totals	29	100	108	100	137	100

TABLE 5

BACKGROUNDS OF SIGNS—FLAT, HIGHLY POPULATED AGRICULTURAL AREA

Background	Number of Signs and Percent of Total					
	Overhead		Shoulder		Combined	
	No.	%	No.	%	No.	%
Sky	208	41.7	54	6.6	262	19.9
Trees						
Dark green	45	9.1	263	32.3	308	23.6
Bright green	4	0.8	54	6.6	58	4.4
Grass						
Tan	12	2.4	24	2.9	36	2.8
Green	9	1.8	17	2.1	26	2.0
Building	20	4.0	29	3.6	49	3.7
Advertising signs	17	3.4	85	10.4	102	7.9
Road	1	0.2	14	1.7	15	1.1
Bridge	89	17.9	132	16.2	221	16.9
Sand	—	—	4	0.5	4	0.1
Dark hill	55	11.0	45	5.5	100	7.7
Sky and building	—	—	—	—	—	—
Sky and bridge	15	3.0	33	4.1	48	3.5
Sky and natural						
Dark	23	4.7	6	7.5	84	6.4
Light tan	—	—	—	—	—	—
Bright green	—	—	—	—	—	—
Red rock	—	—	—	—	—	—
Grey rock	—	—	—	—	—	—
Totals	498	100	815	100	1313	100

TABLE 6

BACKGROUNDS OF SIGNS—VERY HILLY AREA

Background	Number of Signs and Percent of Total					
	Overhead		Shoulder		Combined	
	No.	%	No.	%	No.	%
Sky	32	31. 3	16	4. 2	48	10. 0
Trees						
Dark green	9	8. 8	98	25. 9	107	22. 3
Bright green	—	—	13	3. 4	13	2. 7
Grass						
Tan	5	4. 9	71	18. 7	76	15. 8
Green	2	2. 0	9	2. 4	11	2. 3
Building	2	2. 0	4	1. 1	6	1. 2
Advertising signs	4	3. 9	12	3. 2	16	3. 3
Road	—	—	17	4. 5	17	3. 5
Bridge	20	19. 6	47	12. 4	67	13. 9
Sand	—	—	4	1. 1	4	0. 8
Dark hill	15	14. 8	64	16. 9	79	16. 5
Sky and building	—	—	2	0. 5	2	0. 4
Sky and bridge	—	—	—	—	—	—
Sky and natural						
Dark	13	12. 7	21	5. 4	34	7. 1
Light tan	—	—	1	0. 3	1	0. 2
Bright green	—	—	—	—	—	—
Red rock	—	—	—	—	—	—
Grey rock	—	—	—	—	—	—
Totals	102	100	379	100	481	100

TABLE 7

BACKGROUNDS OF SIGNS—MOUNTAINOUS AREA

Background	Number of Signs and Percent of Total					
	Overhead		Shoulder		Combined	
	No.	%	No.	%	No.	%
Sky	—	—	1	0. 3	1	0. 3
Trees						
Dark green	3	18. 8	146	45. 4	149	44. 2
Bright green	3	18. 8	12	3. 7	15	4. 5
Grass						
Tan	—	—	21	6. 6	21	6. 2
Green	—	—	3	0. 9	3	0. 9
Building	—	—	5	1. 6	5	1. 5
Advertising signs	—	—	5	1. 6	5	1. 5
Road	4	25. 0	22	6. 9	26	7. 7
Bridge	4	25. 0	17	5. 3	21	6. 1
Sand	—	—	10	3. 1	10	3. 0
Dark hill	—	—	16	5. 0	16	4. 7
Sky and building	—	—	—	—	—	—
Sky and bridge	—	—	—	—	—	—
Sky and natural						
Dark	2	12. 4	10	3. 1	12	3. 6
Light tan	—	—	1	0. 3	1	0. 3
Bright green	—	—	4	1. 2	4	1. 2
Red rock	—	—	8	2. 5	8	2. 4
Grey rock	—	—	40	12. 5	40	11. 9
Totals	16	100	321	100	337	100

TABLE 8

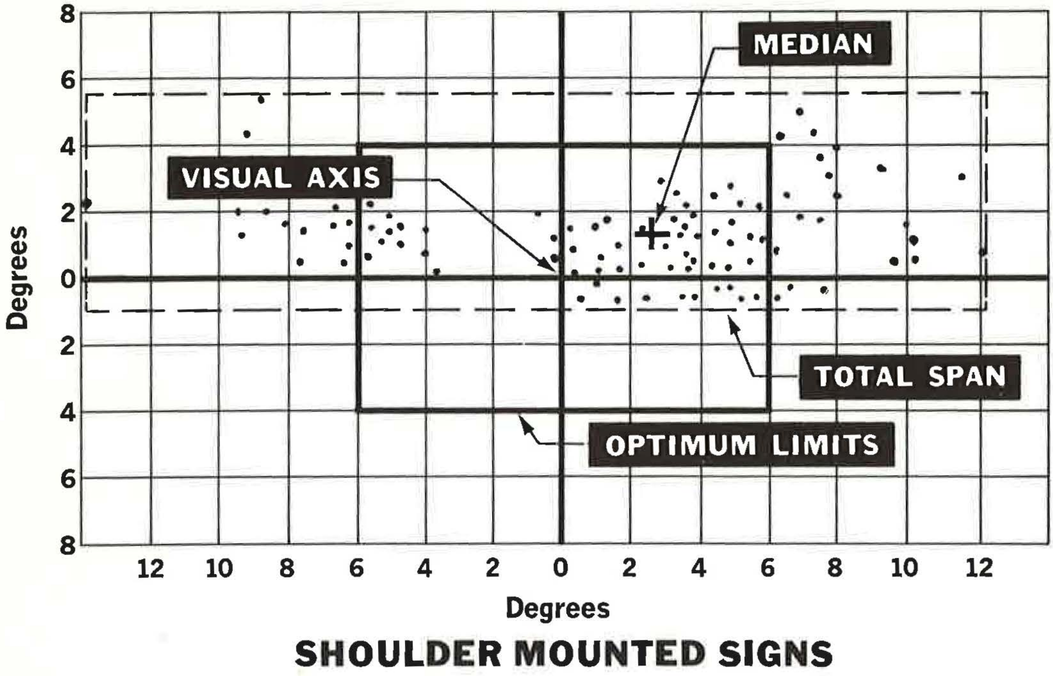
BACKGROUNDS OF SIGNS BY FACILITY TYPE

Background	Facility Type					
	At Grade		Depressed		Elevated	
	No.	%	No.	%	No.	%
Sky	602	18.3	61	17.6	114	29.0
Trees						
Dark green	820	24.8	38	10.9	74	18.8
Bright green	111	3.3	3	0.8	7	1.8
Grass						
Tan	163	4.9	2	0.6	10	2.5
Green	101	3.0	—	—	1	0.2
Building	111	3.3	59	17.0	51	12.9
Advertising signs	138	4.2	8	2.3	11	2.8
Road	72	2.2	8	2.3	3	0.8
Bridge	450	13.7	115	33.2	63	16.0
Sand	47	1.4	—	—	1	0.2
Dark hill	222	6.7	1	0.3	8	2.0
Sky and building	8	0.2	15	4.3	12	3.1
Sky and bridge	120	3.6	32	9.2	13	3.3
Sky and natural						
Dark	267	8.0	5	1.5	26	6.6
Light tan	6	0.2	—	—	—	—
Bright green	27	0.8	—	—	—	—
Red rock	8	0.2	—	—	—	—
Grey rock	40	1.2	—	—	—	—
Totals	3313	100	347	100	394	100

TABLE 9

BACKGROUNDS OF SIGNS BY ROADWAY ENVIRONMENT

Background	Roadway Environment					
	Rural		Suburban		Business	
	No.	%	No.	%	No.	%
Sky	247	14.2	491	24.8	39	11.6
Trees						
Dark green	498	28.7	418	21.2	16	4.8
Bright green	32	1.8	83	4.2	6	1.8
Grass						
Tan	120	6.9	53	2.7	2	0.6
Green	55	3.2	47	2.4	—	—
Building	21	1.2	118	6.0	82	24.4
Advertising signs	35	2.0	98	4.9	24	7.1
Road	47	2.7	26	1.3	10	3.0
Bridge	190	10.9	322	16.3	116	34.6
Sand	43	2.5	5	0.3	—	—
Dark hill	156	9.0	75	3.8	—	—
Sky and building	2	0.1	17	0.8	16	4.7
Sky and bridge	50	2.9	91	4.6	24	7.1
Sky and natural						
Dark	164	9.4	133	6.7	1	0.3
Light tan	6	0.3	—	—	—	—
Bright green	27	1.5	—	—	—	—
Red rock	40	2.3	—	—	—	—
Grey rock	8	0.4	—	—	—	—
Totals	1741	100	1977	100	336	100



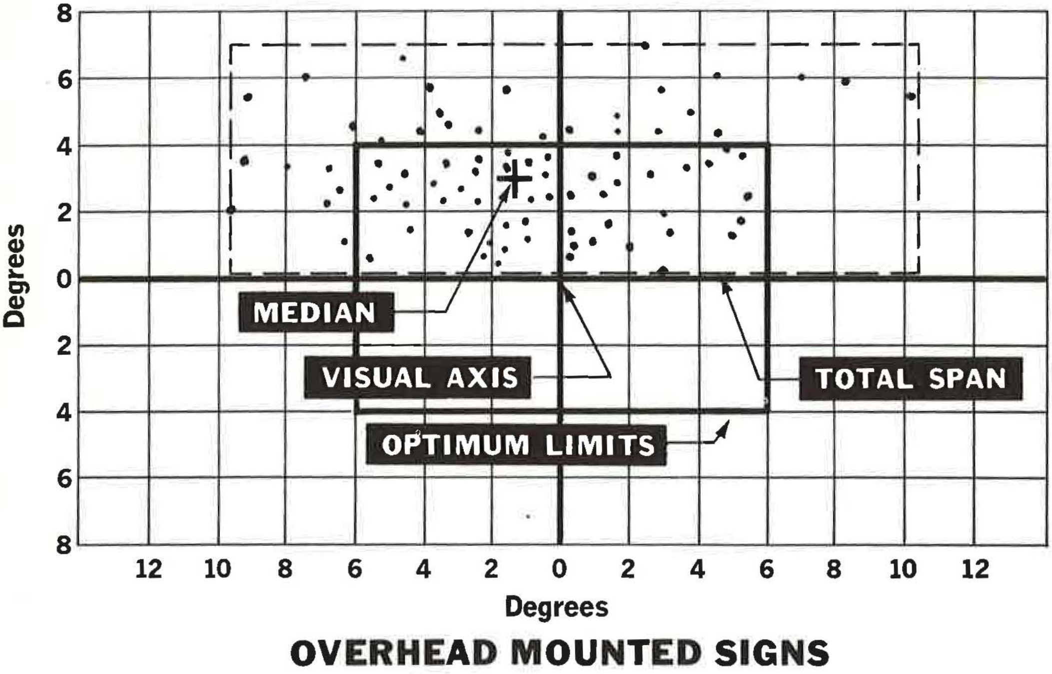
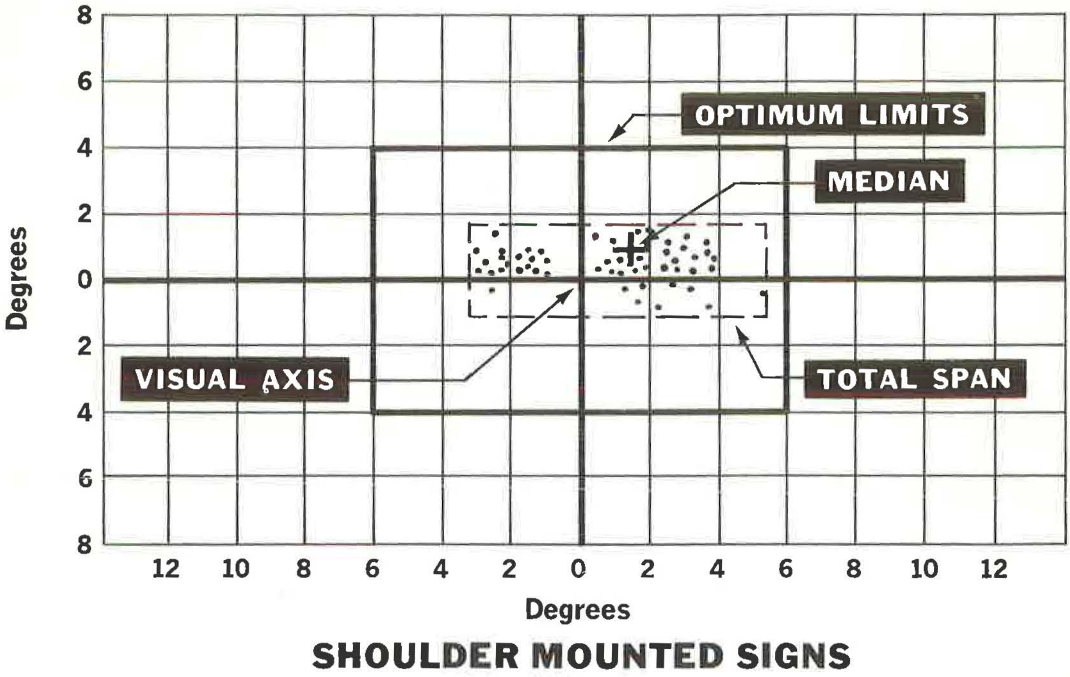


Figure 3. Angular position of traffic signs—gently rolling area.



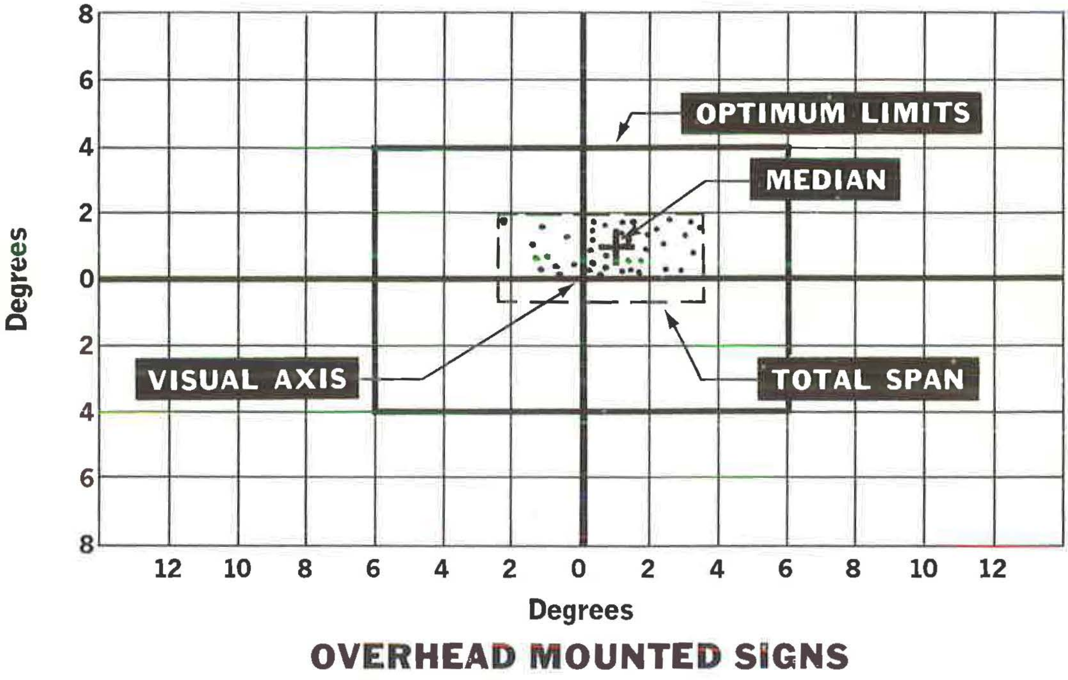
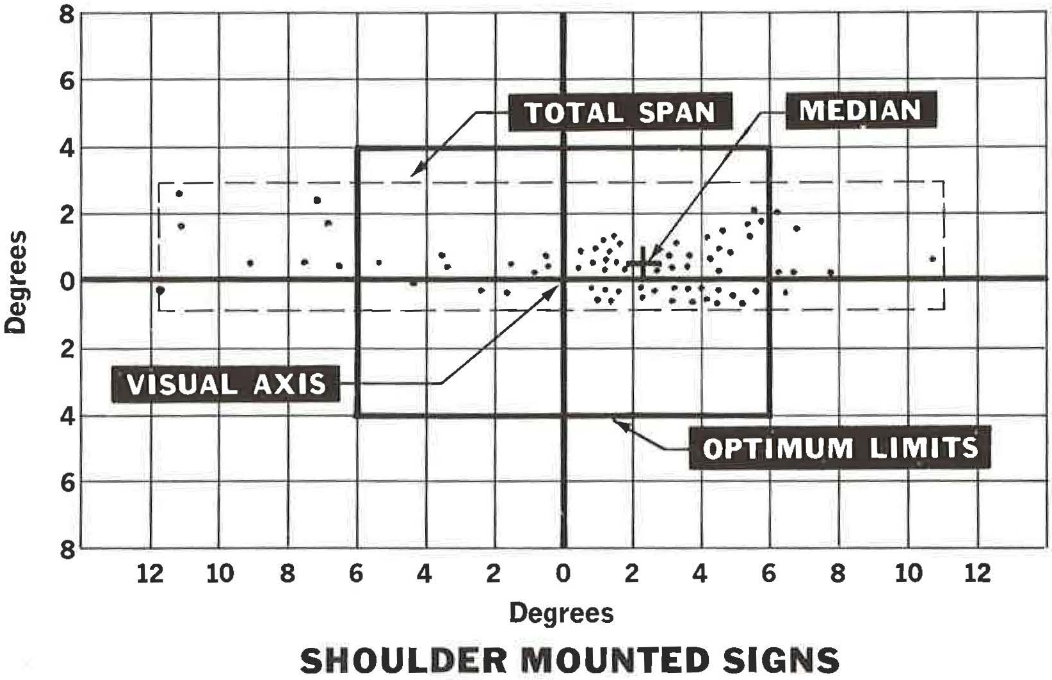


Figure 4. Angular position of traffic signs—flat area.



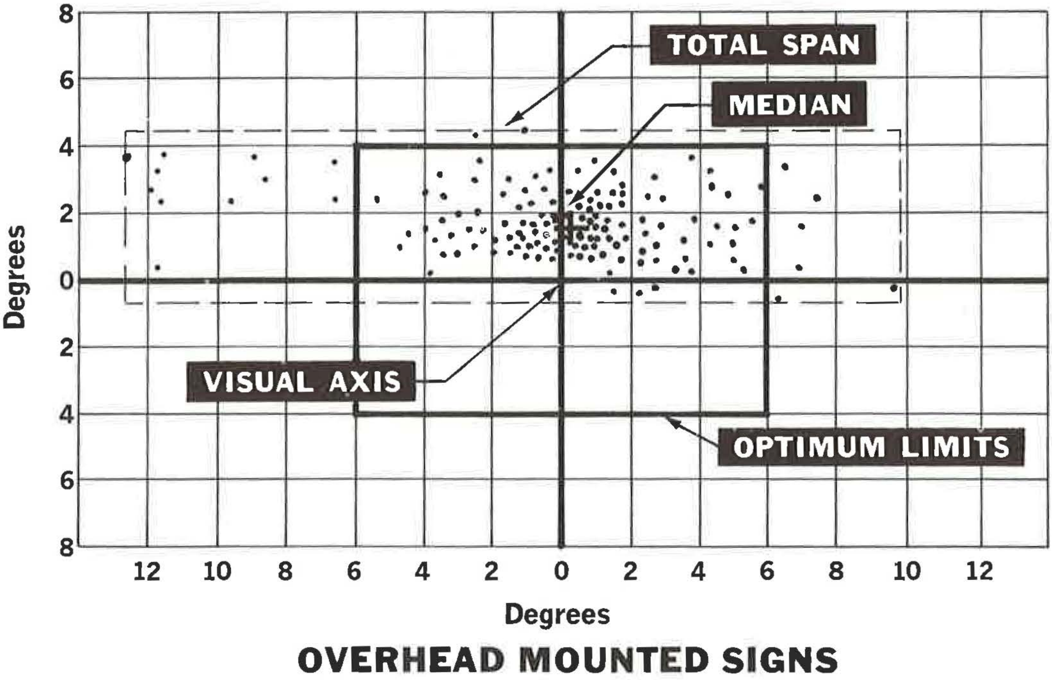
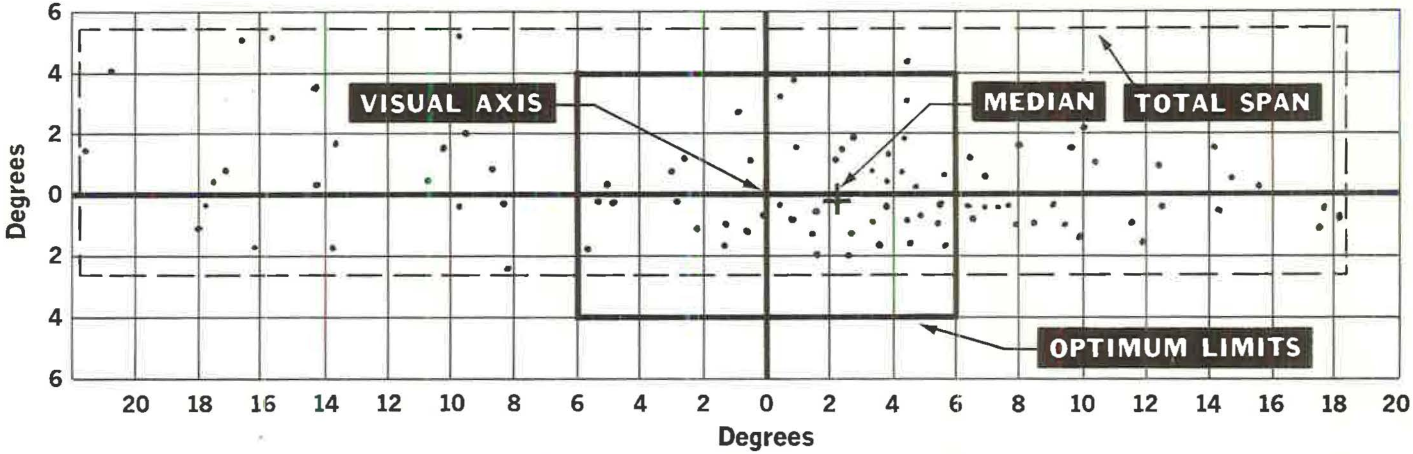
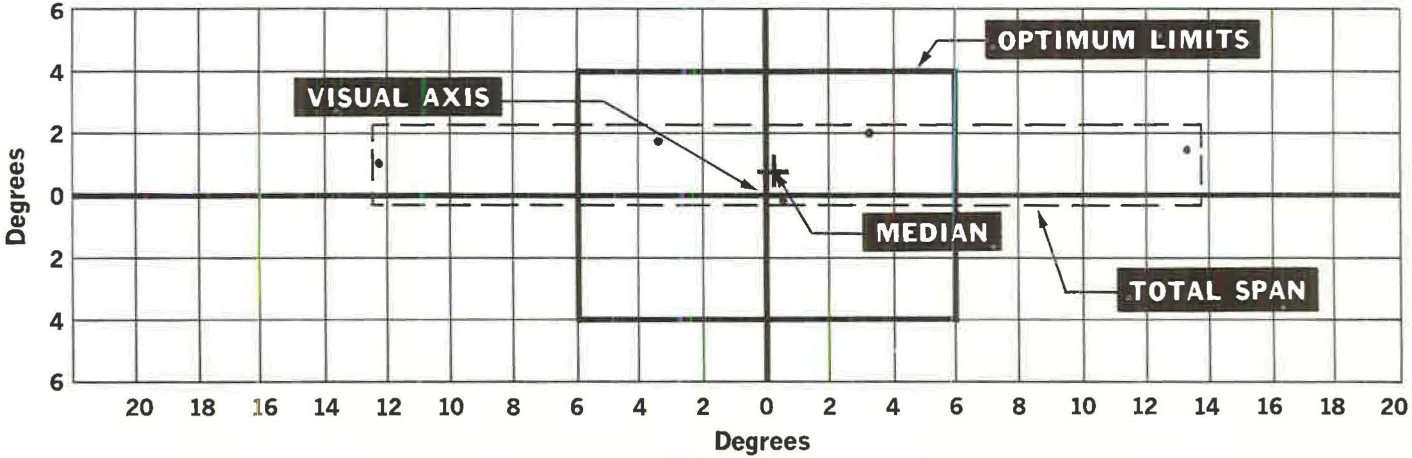


Figure 5. Angular position of traffic signs—metropolitan area.



SHOULDER MOUNTED SIGNS



OVERHEAD MOUNTED SIGNS

Figure 6. Angular position of traffic signs—mountainous area.

TABLE 10

SIGNS HAVING GREATER THAN OPTIMUM ANGULAR DISPLACEMENT[a]

Area Description	Sign Installation	Percent Having Greater Than Optimum Displacement[a]
Mountainous	Shoulder	53
Mountainous	Overhead	29
Metropolitan	Shoulder	16
Metropolitan	Overhead	10
Flat terrain	Shoulder	0
Flat terrain	Overhead	0
Gently rolling	Shoulder	37
Gently rolling	Overhead	27

[a] Optimum angular displacement is within 4 deg vertical and 6 deg horizontal from the visual axis.

The shoulder-mounted distributions in Figures 3 and 4 exhibit two distinct patterns. A fairly large number of signs were installed in the median area to the left of the motorist, thus explaining the concentration to the left of the visual axis in the distributions.

SUMMARY AND CONCLUSIONS

The ability of a sign to compel a motorist's attention in the daytime is related to the background with which it must compete. The first phase of this study determined the nature and frequency of existing sign backgrounds for representative areas. The results revealed that the most frequent background against which a sign appears is dark trees, occurring 23.1 percent of the time. A sky background and a bridge background were the next most frequent with 19.1 and 15.8 percent respectively. Overhead signs had a somewhat higher incidence of sky backgrounds than shoulder-mounted signs, which were predominantly seen against a dark tree background.

References cited suggest limits for maximum angular displacement of signs relative to the driver's visual axis. The second phase of this study consisted of determining angular position of existing signs and comparing data obtained with the suggested limits specified. In areas where the terrain is flat, sign position falls well within the suggested limits. In metropolitan areas and in gently rolling terrain, the percentage of signs having greater than optimum angular displacement ranges from 10 to 37 percent. The mountainous area is most severe, with 53 percent of the shoulder-mounted signs falling outside the optimum range.

The results of this study provide basic information on the nature and frequency of traffic sign backgrounds and establish the need for improved sign positioning if angular position relative to the driver's visual axis is to be optimum. The information should be of interest in the design and placement of traffic signs for maximum effectiveness and attention value.

REFERENCES

1. Matson, T. M., Smith, W. S., and Hurd, F. W. Traffic Engineering. McGraw-Hill, New York, Toronto, London, 1955.
2. Hanson, D. R., and Dickson, A. D. Significant Visual Properties of Some Fluorescent Pigments. Highway Research Record 49, 1963, pp. 13-29.
3. Forbes, T. W. Effect of Sign Position and Brightness on Seeing Simulated Highway Signs. Highway Research Record 164, 1967, pp. 29-37.
4. Kingslake, R. Applied Optics and Optical Engineering. Academic Press, New York and London, 1965.

5. Chapanis, A. How We See: A Summary of Basic Principles. Chapter 1, pp. 3-60, In Panel on Psychology and Physiology, Committee on Undersea Warfare: A Survey Report on Human Factors in Undersea Warfare. National Research Council, Washington, D. C., 1949.
6. Greenshields, B. D. Traffic Engineering Handbook. Institute of Traffic Engineers, Washington, D. C., 1965.
7. Breckenridge, R. P. Modern Camouflage. Farrer & Rinehart, New York and Toronto, 1942.