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FOREWORD

The papers and discussions in this RECORD have one major, common concern: better visibility for drivers on the highway. The papers deal with street lighting, signs, and delineation and will be of interest to those involved in sign and lighting design and operation as well as to those concerned with vision per se. Administrators responsible for funding lighting programs can also find helpful information in the papers dealing specifically with roadway lighting.

Walton and Rowan present a total design process for roadway lighting. The process involves visual information needs of motorists, warranting conditions for lighting, guidelines for lighting design, and cost-effective priorities for fund expenditures. The priority model presented is based on lighting effectiveness, vehicles or people served, lighting intensity, roadway mileage, and total annual lighting costs. The authors conclude that their process is a rational approach through which current practice could be revised. The three discussants of this paper are generally complimentary regarding the extent to which Walton and Rowan's work is useful but suggest areas not considered in their total design process.

Stark discusses 6 major studies of the effects of illumination on accidents. Wide variability in accident rate ratios before and after lighting lead to several precautions that the author feels must be taken in all such studies.

Forbes and Vanosdall report some rather basic visual ability data from a series of tests on 371 subjects under conditions of simulated night-driving luminance and under ordinary lighting conditions. Their results relate to age characteristics of the subjects and should be useful to all concerned with better seeing by drivers at night.

By collecting and analyzing the eye movements of drivers under actual driving situations for more than 400 Interstate highway signs, Rockwell and Bhise attempted to evaluate the signs in terms of the driver's sign-reading behavior as related to the signs, the highway, and the traffic situations. The prime motive of their research was to develop a methodology for using the eye-marker camera in the evaluation of signs. They conclude that the camera can be so used and that its use can lead to a better understanding of the many different factors that affect sign-reading behavior. Thought-provoking discussions point to some of the shortcomings of eye-marker camera use but also suggest ways to better use this important research tool in future evaluation of highway signs.

Yu and Arnn report the findings of a national state-of-the-art survey of roadside delineation concepts. The authors discuss evaluation criteria and attempt to formulate a uniform selection process for optimum delineation treatment under given conditions.

CONTENTS

A TOTAL DESIGN PROCESS FOR ROADWAY LIGHTING

Ned E. Walton and Neilon J. Rowan, Texas Transportation Institute, Texas A&M University

The design process for roadway lighting involves complex interrelations among visual information needs, warranting conditions for lighting, guidelines for lighting design, and cost-effective priorities for fund expenditures. This paper presents a lighting procedure based on information needs of night drivers as related to those interrelations. A framework, consisting of information needs produced by various traffic facility characteristics, is established for development of the design process. The information needs are presented as the requirements to be satisfied by roadway lighting, and the traffic facility characteristics producing the needs serve as the justification or warranting conditions for the installation of lighting. The number of warranting conditions is used as the determinant of design criteria and the basis for cost-effective priorities. A priority model is presented based on lighting effectiveness (the reduction of warranting conditions through the use of roadway lighting), vehicles or people served, lighting intensity, roadway mileage over which the people are served, and total annual lighting costs. The priority model favors those facilities with high warranting conditions that can be lighted most economically. It is concluded that the total design process is a rational approach through which current practices can be revised.

•UNDER present technological and economic conditions, fixed roadway lighting probably offers the most comprehensive means of correcting situations of poor visual environments at night. Roadway lighting practices through the years have indicated that lighting, when properly applied, can provide quick, accurate, and comfortable seeing conditions for the night driver and can result in an overall improvement in highway accident statistics.

Although the state of the art in roadway lighting has progressed dramatically in the past few decades, there remains the need to systematically integrate all of the complex interrelations that exist in the roadway lighting design process. As of yet, there is no comprehensive process for roadway lighting design that adequately relates to the visual needs of the driver. Needs for lighting are specified in terms of traffic volumes, accident experience, and characteristics of abutting property. Those factors in turn serve as warranting conditions, and the warrants then provide the justification for lighting. Design criteria are specified in broad terms of lighting a roadway surface rather than of providing an environment suitable to the driver. Priorities for lighting installations are normally based on accident experience, traffic volume, or political influence.

Ideally, the total design process should be based on requirements for a suitable visual environment. If roadway lighting is to serve its basic function of improving the driver's visual environment, elements of the environment must be identified and a method established for determining the driver's needs. When these conditions are specified, it will be possible to rationally consider requirements for a suitable visual environment that can be provided by fixed roadway lighting. Apparently, there is a need to identify or specify the requirements of the night-driving visual environment.

Publication of this paper sponsored by Committee on Visibility.

The requirements in turn must be systematically integrated for the purpose of developing design procedures that will assist the designer and administrator in meeting those requirements through roadway lighting.

The objectives of this paper are (a) to present a compendium of roadway lighting technology, research, and practice and (b) to present a total roadway lighting design process based on the most recent lighting technology, research, and practice.

DEFINITION OF TOTAL ROADWAY LIGHTING DESIGN PROCESS

There are 5 elements that constitute the total roadway lighting design process:

1. Informational needs that are to be satisfied by the provision of fixed roadway lighting (requirements for a suitable visual environment);
2. Justification for lighting (warranting conditions);
3. Design criteria for lighting (provisions for the informational needs);
4. Realization of design criteria (illumination design); and
5. Cost-effectiveness priority determination (which lighting designs are most effective and should be installed first).

Heretofore, these elements have stood alone and were never integrated into a total system. Incorporated into an overall program, the 5 elements will provide a tool with which the designer and the administrator can carry a lighting program from the investigation of needs to the implementation of the final project.

Requirements for a suitable visual environment, warrants for lighting installation, guidelines for lighting design, and cost-effectiveness priorities are all interrelated to the extent that positive separation is difficult, if not impossible. Therefore, it is desirable that the design process be developed around a common framework that is responsive to and compatible with all elements of the process. The common framework is the informational basis of visual communication as related to driving performance under various traffic facility conditions. That framework can provide for a systematic treatment of all elements that constitute the total design process.

The requirement for a suitable visual environment provided by fixed roadway lighting is the visual access of information needs necessary for safe and efficient vehicle operation. Provision of visual access and resulting comfort to the driver are positive benefits to be derived.

On a traffic facility the need for lighting increases as the need for information increases. Justifications or warrants for lighting are, therefore, informational needs, and those informational needs are influenced by the characteristics of the traffic facilities. A determining factor for roadway lighting design criteria is the extent to which informational needs can be satisfied by roadway lighting. The level of lighting intensity should be proportional to the level of information needs.

Access to needed visual information provided by roadway lighting also serves as a measure of benefits or effectiveness. Optimum cost effectiveness occurs when the access to information is provided to more people at an equal cost. This optimal solution is also a priority indicator.

Thus, conceptually, the total design process can be defined and developed in terms of visual information needs.

PREVIOUS RESEARCH AND PRACTICE RELATED TO THE TOTAL DESIGN PROCESS

Visual Information Needs

A number of attempts have been made to characterize driving performance in terms of the amount of information drivers gather from the environment and how it relates to vehicular control. King and Lunenfeld (16) determined that visual information needs fell into 3 categories: microperformance needs associated with lane control and velocity; situational performance needs associated with interaction with the roadway, other vehicles, and the environment; and macroperformance needs associated with navigation from an origin to a destination.

Gordon (13), Senders (22), and Rockwell, Ernst, and Rulon (18) have determined that microperformance visual needs are satisfied by vehicle headlighting. Rowan and Walton (19) and Woods and Rowan (26) provided information to conclude that navigational needs (primarily signing) are satisfied by a combination of retroreflection and headlights or external sign lighting. Walton (27) concluded that navigational information needs are those most closely associated with fixed roadway lighting. Walton (27) used a multidisciplinary study team consisting of various professionals and lay drivers to determine the visual information needs to be provided by fixed roadway lighting on both controlled-access and non-controlled-access facilities. Walton (27) also reports the traffic facility characteristics producing or contributing to the visual information needs.

Warrants for Lighting

Fixed roadway lighting practices in the United States vary from state to state and from city to city. However, there are 2 accepted standards of practice: An Informational Guide for Roadway Lighting (3) and American National Standard Practice for Roadway Lighting (2). The Informational Guide is used by the state highway departments, and the Standard Practice is used by most cities that have established lighting programs.

The Informational Guide cites the following conditions as those warranting or justifying lighting:

1. Freeway lighting—adjacent street grid system with lighting, developmental lighting, close interchange spacing, average daily traffic of 30,000 vehicles, high night-to-day accident experience, and willingness of local government to pay costs;
2. Interchange lighting—adjacent lighting at the interchange and average daily traffic of 5,000 vehicles and more depending on the specific design; and
3. Roads other than freeways—in general, locations where the respective governmental agencies concur that lighting will contribute substantially to the efficiency, safety, and comfort of vehicular and pedestrian traffic and where resulting benefits, both tangible and intangible, are in the interest of the general public.

The Standard Practice lists the following conditions that should be examined in determining the need and, thus, justification for lighting: types of land use development abutting the roadway or walkway (area classification), type of route (route classification), traffic accident experience, street crime experience and security, and roadway construction features.

These conditions make mention of several important traffic considerations, but there is little indication as to how the conditions relate to driver informational needs and roadway lighting. There is the implication that roadway lighting serves the basic purpose of traffic safety (the prevention of accidents), whereas the informational aspects of lighting should be stressed. It is logical that improvement in the visual information system will improve efficiency of traffic operations, and traffic safety is a by-product of efficiency.

Constructively, the Informational Guide and the Standard Practice do provide some indication of informational needs. That is achieved through area classification (commercial, intermediate, residential, urban, and rural) and route classification (freeways, majors, collectors, locals, and alleys). The implication is that driver informational needs vary with location and type of facility. The primary deficiency is the lack of scaling or relation to various conditions on each type of facility producing or contributing to the need for lighting. Thus, it would be desirable to use traffic facility characteristics that produce or contribute to visual information needs as warranting conditions.

Design Criteria

The horizontal footcandle (HFC) is the primary design criterion specified by the Informational Guide and the Standard Practice. Visual effectiveness is not necessarily directly related to horizontal levels of illumination, but a minimum quantity of light must be provided even under the most favorable conditions before visual contact with the surroundings can be established.

It has been suggested that road luminance be used as the primary criterion in lieu of horizontal footcandles (12). Road luminance is dependent on type of light control used, color and texture of the pavement, angle of incident light, and angle of viewing. Several of these elements may be standardized for design purposes. However, pavement color and texture, which determine reflectance properties, vary greatly among different types and ages of pavement. Ketvirtis (15) has pointed out that a good concrete surface initially can reflect 25 percent of incident light, but that is reduced to 16 or 18 percent by the accumulation of carbon, oil, and chemicals. Asphalt surfaces, on the other hand, have 10 to 11 percent initial reflectance, but later, because of polishing, the reflectance is increased to 12 or 14 percent.

Ketvirtis (15) suggests using an approximation of pavement luminance based on horizontal footcandles and on average coefficient of luminance. This approximation provides a closer relation with actual lighting effectiveness than the method based on horizontal illumination units and yet does not entail point-by-point luminance calculations involving information on reflectance properties that are unavailable, subject to change, or unpredictable because of maintenance pavement overlay practices.

Uniformity of light is another important design criterion recommended by the Informational Guide and the Standard Practice. The ratio of maximum to minimum levels of horizontal footcandles has been considered desirable (15), but average to minimum ratios are now used for the following reasons:

1. Visual adaptation will tend toward the average level;
2. The average level of horizontal illumination is used extensively as a design parameter; and
3. The absolute maximum value is likely to vary greatly with lighting components.

It would be practical at the present time to use average illumination, average reflectance, average to minimum ratios, and maximum to minimum ratios as design criteria. In addition, quality of light can be controlled through existing Standard Practice luminaire designations.

Illumination Design

Illumination design is the process of selecting mounting heights, spacings, and locations for selected luminaire types and light sources to achieve the specified criteria. There are 3 general types of illumination systems that are practical in illumination design: continuous lighting of a roadway section of any length; partial lighting of intersections and interchanges; and area lighting of interchanges. Continuous lighting and partial lighting are normally achieved through what is termed "conventional lighting" with mounting heights ranging from 30 to 60 ft. Area lighting of interchanges is achieved through "high-mast" lighting with mounting heights of 100 to 200 ft (24).

The design criteria may be achieved through the following methods:

1. In the computational approach (2),

$$\text{Average illumination} = \frac{\text{LL} \times \text{CU} \times \text{LMF}}{\text{S} \times \text{W}}$$

where LL = lamp lumens at replacement time, CU = coefficient of utilization, LMF = luminaire maintenence factor, S = luminaire spacing, and W = width of lighting area.

2. In the point-by-point approach (27),

$$E_H = \frac{CP \cos \theta}{d^2}$$

where E_H = illumination at a point, CP = candlepower at angle θ, θ = angle from the vertical through the system to the point, and d = distance from the light source to the point.

3. In the design standards approach (27), typical spacings and mounting heights for specific luminaire types and light sources for various design criteria levels are established based on previous experience or testing.

Very acceptable results may be achieved by using any of these techniques.

Cost-Effectiveness Priorities

A detailed review of research and practice indicates that cost effectiveness is the only method of economic analysis amenable to roadway lighting. All other methods, including the cost-of-time method, benefit-cost method, rate-of-return method, and total-transportation-cost method, involve monetary evaluations of effectiveness. These methods could be used to determine best designs and set priorities, if lighting effectiveness could be measured in dollar terms. Unfortunately, however, it is not possible with the current state of the art to measure even in physical units the effects on motorists of different types and degrees of lighting in different situations much less the value of changes in those physical units in dollar terms.

It appears logical, therefore, that cost effectiveness and priorities be determined on the basis of visual information needs provided by fixed roadway lighting.

DEVELOPMENT OF A TOTAL DESIGN PROCESS

Visual Information Needs

Research was conducted by the Texas Transportation Institute to identify those elements of the night-driving visual environment that are necessary for safe and efficient traffic operations. Knowing those elements that are important to the driver as visual information tasks allows for orderly consideration of the illumination design requirements to satisfactorily accomplish the tasks.

Multidisciplinary teams consisting of professionals and lay drivers were used in Atlanta and Dallas in night-driving situations to identify information needs that should always be provided at night to the driver of a motor vehicle. These needs are given in Table 1 for controlled-access and non-controlled-access facilities. In addition, the teams identified the operational, geometric, and environmental conditions producing or contributing to the visual information needs. Those conditions are given in Table 2.

It is noted at this point that fixed roadway lighting is not a panacea for all visual information needs. There are elements of the visual environment that often can be made adequately visible by vehicle headlights. There are other elements that no amount of fixed lighting will make visible if they are not present or properly maintained (lane lines, edge lines, and delineators). Therefore, it is paramount to state that fixed lighting and traffic control measures cannot be considered independently. It is first necessary to provide adequate pavement markings, delineation, signing, and even design features because fixed roadway lighting can only illuminate and supplement those necessary elements.

Warrants

A basic classification concept has been developed for the treatment of warranting conditions, criteria, and cost-effectiveness priorities. That concept is shown in Figure 1. The geometric, operational, and environmental parameters that produce or contribute to information needs have been broadly categorized. In addition, accident history has been included.

Using this concept and the needs and characteristics given in Tables 1 and 2, a professional team consisting of representatives from traffic characteristics, traffic operations, geometric design, illumination design, and economics established the relative importance of the characteristics to serve as the basic warranting scheme for roadway lighting. The relative importance was determined by field studies, literature, and collective judgment of the professional team. Figure 2 shows an example of the quantifications that were made for use as warranting conditions for non-controlled-access facility lighting. Similar ones were made for lighting of intersections, controlled-access facilities, and interchanges.

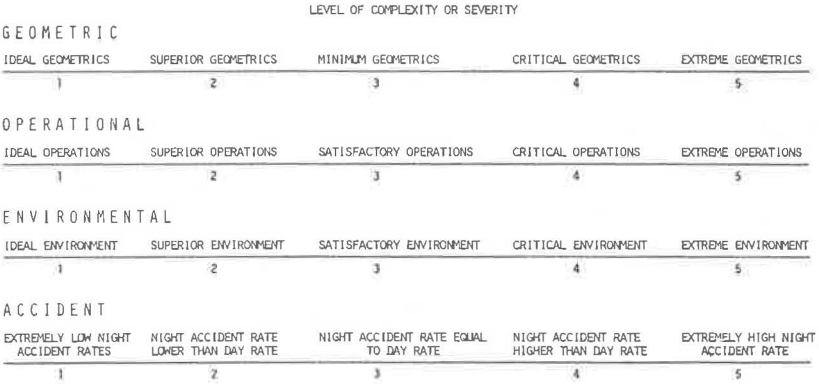
Table 1. Visual information needs to be provided by fixed roadway lighting.

Non-Controlled-Access Facilities	Controlled-Access Facilities	Non-Controlled-Access Facilites	Controlled-Access Facilities
Roadway geometry	Roadway geometry	Shoulders	Shoulders
Roadway surface	Roadway surface	Roadside objects	Roadside objects
Roadway objects	Roadway objects	Curb locations	Vehicles on facility
Roadway edge	Roadway edge	Vehicles on facility	Vehicles on interchanging facilities
Roadway markings	Roadway markings		
Signs	Signs	Pedestrians	Ramp entrances
Signals	Signals on crossroads	Pedestrian crosswalks	Ramp exits
Delineation	Delineation	Sidewalks	Merge points
Intersection location	Intersection location		On-ramp geometry
Channelization outline	Channelization outline		Off-ramp geometry
Access driveways	Curb locations		

Table 2. Traffic facility characteristics producing or contributing to visual information needs.

Location	Geometric	Operational	Environmental
Non-controlled-access facilities	Number of lanes Lane width Median openings Curb cuts Curves Grades Sight distance Parking lanes	Signals Left-turn signals and lanes Median width Operating speed Pedestrian traffic	Development Type of development Development setback Adjacent lighting Raised curb medians
Non-controlled-access intersections	Number of legs Approach lane width Channelization Approach sight distance Grades on approach Curvature on approach Parking lanes	Operating speed on approval Type of control Channelization Level of service Pedestrian traffic	Development Type of development Adjacent lighting
Controlled-access facilities	Number of lanes Lane width Median width Shoulders Slopes Curves Grades Interchanges	Level of service	Development Development setback
Controlled-access interchanges	Ramp types Channelization Frontage roads Lane width Median width Number of freeway lanes Main lane curves Grades Sight distance	Level of service	Development Development setback Crossroad lighting Freeway lighting

Figure 1. Traffic facility classification.



The classification factors listed in the first column are the geometric, operational, and environmental factors identified by the multidisciplinary teams in field studies at Atlanta and Dallas. Accident history is also included as a classification factor. The next 5 columns are quantifications of the classification factors as assigned by the professional team. The quantifications correspond to the basic scheme shown in Figure 1. The next 2 columns are weighting factors assigned by the professional team to indicate the relative importance of the various classification factors under lighted and unlighted conditions, and the following column represents the difference between the weightings for those 2 conditions. That difference is the measure of effectiveness that can be achieved through the provision of fixed roadway lighting. The final column is the score for each of the classification factors and is obtained by multiplying the rating of each factor by the difference in unlighted and lighted weightings. The total of all scores represents the warranting points or conditions for fixed roadway lighting. This total is compared to the minimum warranting condition points listed at the bottom; if the minimum points are exceeded, roadway lighting is warranted.

The minimum warranting points at the bottom of the figure were obtained by rating all classification factors at average conditions (3 on the scale of 1 to 5). Any combination of ratings that will produce a total exceeding the minimum would warrant roadway lighting. The degree to which the total points exceed the minimum serves as the basis for design criteria and priorities discussed in the following sections.

It may be desirable for those using the process to set their own minimum level. The true effect of doing so is minimal if a priority procedure is followed in conjunction with the warrants. If this is done, those facilities with greatest needs will still be scheduled first for implementation and will receive the available funds.

Design Criteria

The basic illumination level for a lighting project should correspond to the minimum levels recommended by the Informational Guide and the Standard Practice. These values, given in Table 3 are considered the basic values because they represent a minimum of modifying conditions (geometry, operations, environment). Although these minimum values have little direct physiological or vision basis, they have been well established through many years of research and practice. Provision should be made, however, to adjust them on the basis of warranting conditions. For a roadway receiving a score exactly that of the minimum warranting points, the level of illumination would be the basic value given in Table 3. For any other number of points exceeding the minimum, the level of illumination may be computed as

$$w = \frac{I_{BASIC} \times E}{MW} \tag{1}$$

where

w = level of illumination, in HFC;

I_{BASIC} = basic values given in Table 3;

E = total warranting points on a facility; and

MW = minimum warranting points for a given type of facility.

For example, if a non-controlled-access facility received a total of 127 points, the level of illumination would be

$$\begin{aligned} w &= \frac{I_{BASIC} \times E}{MW} \\ &= \frac{(1.0)\ (127)}{(85)} \\ &= 1.55 \text{ HFC} \end{aligned}$$

Figure 2. Classification for non-controlled-access facility lighting.

Classification Factor	Rating 1	2	3	4	5	Unlit Weight (A)	Lighted Weight (B)	Difference (A-B)	Score [Rating X(A-B)]
Geometric									
Number of lanes	4 or <	–	6	–	8 or >	1.0	0.8	0.2	
Lane width, ft	12	12	11	10	9 or <	3.0	2.5	0.5	
Median openings per mile	< 4.0 or 1-way operation	4.0-8.0	8.1-12.0	12.0-15.0	> 15.0 or no access control	5.0	3.0	2.0	
Curb cuts, percent	< 10	10-20	20-30	30-40	> 40	5.0	3.0	2.0	
Curves, deg	< 3.0	3.1-6.0	6.1-8.0	8.1-10.0	> 10	13.0	5.0	8.0	
Grades, percent	< 3	3.0-3.9	4-4.9	5.0-6.9	7 or >	3.2	2.8	0.4	
Sight distance, ft	> 700	500-700	300-500	200-300	< 200	2.0	1.8	0.2	
Parking	Prohibited both sides	Loading zones only	Off-peak only	Permitted one side	Permitted both sides	0.2	0.1	0.1	
Total									———
Operational									
Signalized intersections	All major	Substantial majority	Most major	About half	Not many	3.0	2.8	0.2	
Intersections with left-turn lane and signal	All major or 1-way operation	Substantial majority	Most major	About half	Infrequent turn bays or undivided streets	5.0	4.0	1.0	
Median width, ft	30	20-30	10-20	4-10	0-4	1.0	0.5	0.5	
Operating speed	25 or <	30	35	40	45 or >	1.0	0.2	0.8	
Pedestrians at night/mile	Few or none	0-50		100-200	200	1.5	0.5	1.0	
Total									———
Environmental									
Development, percent	0	0-30	30-60	60-90	100	0.5	0.3	0.2	
Predominant type of development	Undeveloped or backup design	Residential	Half-residential and/or commercial	Industrial or commercial	Strip industrial or commercial	0.5	0.3	0.2	
Setback distance, ft	< 200	150-200	100-150	50-100	< 50	0.5	0.3	0.2	
Advertising or area lighting, percent	None	0-40	40-60	60-80	100	3.0	1.0	2.0	
Raised curb median	None	Continuous	At all intersections	At signalized intersections	Few locations	1.0	0.5	0.5	
Crime rate	Extremely low	Lower than city avg	City avg	Higher than city avg	Extremely high	1.0	0.5	0.5	
Total									———
Accidents									
Ratio of night to day accident rates	< 1.0	1.0-1.2	1.2-1.5	1.5-2.0	2.0[a]	10.0	2.0	8.0	———
Grand total									

[a] Continuous lighting warranted.

Table 3. Recommendations for average maintained horizontal illumination.

Location	Horizontal Footcandles	Lux
Controlled-access facilities, including major interchanges	0.6	6.0
Non-controlled-access facilities		
Primary arterials, expressways, and major highways	1.0	11.0
Secondary arterials, major collectors, and secondary highways	0.6	6.0
Minor collectors and minor commercial roads	0.4	4.0
Local roads, streets, and alleys	0.2	2.0

To account for differences in pavements, data from the International Recommendations for the Lighting of Public Thoroughfares (14) may be used. Those data, along with a conceptual rating similar to that shown in Figure 1, can be used to scale or modify the level of illumination. By assigning a unit value to average pavement condition, one can establish a weighted multiplier for each of 5 pavement classifications. The multipliers are as follows:

Pavement	Multiplier
Extremely light	0.80
Above average	0.90
Average	1.0
Below average	1.2
Extremely dark	1.4

The illumination values for a facility can then be determined by

$$w = \frac{I_{BASIC} \times E \times R_{PVT}}{MW} \tag{2}$$

where R_{PVT} = pavement condition multiplier. From the previous example, the design level of lighting for extremely dark pavements would be

$$w = \frac{(1.0)\ (1.27)\ (1.4)}{(85)}$$

$$= 2.17 \text{ HFC}$$

In addition to this criterion, uniformity should correspond to the accepted 3 to 1 ratio. Also a ratio of maximum to minimum illumination of 6 to 1 should be specified.

Areas other than the roadway surface should also be illuminated. The informational needs and traffic facility characteristics previously discussed indicate many visual tasks adjacent to the roadway. Inasmuch as a distance of 30 ft from the traveled way has been established as a width of frequent errant excursions by vehicles, it is recommended that this roadside area be illuminated to no less than the minimum intensity on the traveled way.

Illumination Design

Any of the 3 basic design approaches discussed previously can be used to design an illumination system. Points to be considered are primarily mounting height and spacing as related to the design criteria. Higher heights usually provide a better distribution of light over larger roadway areas and, thus, provide a more economical installation (17). The higher heights also permit the use of the larger, more efficient light sources. On the other hand, the maximum mounting height is frequently determined on the basis of effective working height of maintenance equipment. As a general rule, the mounting height selected for a given design will be the maximum height commensurate with the average level of illumination and maintenance constraints.

A final consideration in illumination design is the location of luminaire supports with respect to the traveled way. It is recommended that luminaire supports be located as far as practicable from the through traffic lanes for 2 reasons: (a) The probability of impact is reduced and (b) less glare and better uniformity are achieved when the luminary is mounted over the shoulder or curb rather than over the traffic lanes.

In addition, all luminaire supports in areas other than low-speed, high-pedestrian situations should be the breakaway type. Several references are available for determining proper breakaway supports (17, 25).

Cost-Effective Priority Determination

Once the visual needs, warranting conditions, and design criteria are established, the final step in the total design process is to determine the most effective designs and to set priorities for implementation. The final step provides the designer and the administrator a tool for expending public funds in a manner such that maximum effectiveness is achieved.

In general, the following cost-effectiveness procedure is used for evaluating designs and setting priorities for a particular situation:

1. Specify several lighting designs that give the desired level of lighting effectiveness. (For a more complete optimization procedure, consider several levels of effectiveness.)
2. For each feasible lighting configuration, specify different circuits that are feasible for that configuration. Estimate the cost of each of these circuits and suboptimize by choosing the least costly circuit for each design. It is also possible to further suboptimize by considering different user-utility ownership arrangements for each circuit and to choose the least costly (or "best" in some other sense) ownership arrangement for each circuit. Then compare these least costly ownership arrangements to obtain the least costly circuit for each lighting configuration.
3. Summarize the effectiveness and cost for each feasible lighting design and choose, using this summarized information together with judgment, the "best" design. (This "best" design, together with its effectiveness and cost, is the design that is used in priority determinations.)
4. Determine the number of people that will benefit from the lighting installation (night traffic) and the distance over which they will benefit (the number of lane-miles). Then, using those data, along with the best design, effectiveness, and cost, assign a priority for installation.

A cost-effectiveness priority model has been developed for use in achieving the above steps. This model is expressed as

$$P_x = \frac{E \times \frac{NADT}{n} \times L \times \frac{F}{w}}{AC} \qquad (3)$$

where

P_x = priority index for a given lighting installation;
E = calculated lighting effectiveness (total warranting points for the given facility);
$NADT$ = design night average daily traffic;
n = number of lanes;
L = affected lane-miles of lighting;
F = actual level of average illumination produced by the best design;
w = warranted design level of illumination as computed by Eq. 2; and
AC = total annual costs for the best design, including installation, operation, maintenance, and vehicle-pole collision accident costs.

Several sources are used to provide the input data for the model. Data such as those shown in Figure 2 are used to determine E, Eq. 2 is used to determine w, and forms shown in Figures 3, 4, and 5 are used to summarize the other data. In addition, forms provided by Cassel and Medville (8) may be used for detailed equipment specification and cost data. The form shown in Figure 3 provides a total summary for each lighting project. Form 2 (Fig. 4) can be used to summarize cost and effectiveness, and form 3 (Fig. 5) can be used to specify roadway lighting configurations. Expected accident costs for vehicles hitting lighting installations should be calculated and can be done by using the procedure developed by McFarland and Walton (17). The priority index model will favor those facilities with high warranting conditions that can be lighted most economically.

Figure 3. Summary form.

Identification Number:

(1) Facility Location:

(2) Facility Type:

(3) Road Length:

(4) Road Width(s):

(5) Number of Lanes (n):

(6) Affected Lane Miles (L):

(7) Design Average Daily Traffic:

(8) Design Night Average Daily Traffic (NADT):

(9) Warranted Illumination Level, ave. maintained footcandles (w):

(10) Calculated Lighting Effectiveness or total warranting points (E):

(11) Multiplier = (ExNADTxL)/(nxw):

(12) Analysis Period (years):

(13) Interest Rate (%):

(14) Desired Uniformity Ratio(s):

<u>Best Design</u>

(15) Configuration Number:

(16) Priority Index:

(17) Annual Cost:

(18) Ave. Maintained Footcandles:

(19) Uniformity Ratio(s):

Figure 4. Cost and effectiveness summary form.

IDENTIFICATION NUMBER:

								EFFECTIVENESS				
			ANNUAL COST[c]								Priority Index[d]	
(1) Configuration Number	(2) Circuit Number[a]	(3) Initial Capital Cost	(4) Equivalent Capital[b]	(5) Maintenance and Power	(6) Subtotal (4) + (5)	(7) Light Pole Accident	(8) Total (6) + (7)	(9) Ave. Foot Candles Actual (F)	(10) Min. Foot Candles	(11) Ave./Min. Ratio (9)/(10)	(12) Multiplier x Col. (9) ÷ Col. (6)	(13) Multiplier x Col. (9) ÷ Col. (8)
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

[a] Circuit number chosen as best for given configurations.
[b] Column (3) multiplied by capital recovery factor for chosen analysis period and interest rate.
[c] For best ownership arrangement considered.
[d] "Multiplier" is taken from Form 1.

Figure 5. Roadway lighting configuration summary form.

IDENTIFICATION NUMBER:

	Lamp Characteristics			Pole Characteristics							Illumination (footcandles)		
Configuration Number	Type	ASA Designation	Light Output (lumens)	Power (watts)	Mounting Height (feet)	Overhand (feet)	Luminaire Type[a]	Light Distribution Type	Arrangement	Spacing (feet)	Average	Minimum	Uniformity Ratio
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													

[a] HB = horizontal burning.
[b] SE = standard enclosed.

INTERPRETATION AND APPRAISAL

A total design process, based on efficiency of night visual communications and traffic facility characteristics, has been presented. This commentary reflects an interpretation and appraisal of the process.

1. There are visual information needs associated with each level of performance in the driving task.

During the night, most information needs that can be satisfied by roadway lighting are associated with the situational level of performance. However, in many cases, the inadequacy of positional information (lane lines, edge lines, and delineation) produces the situational needs. If a driver is forced to search for positional information, he has little time left to attend to situational and navigational tasks. It is necessary, therefore, to provide adequate traffic control and even design features, because fixed roadway lighting can only illuminate and supplement those necessary elements.

2. Geometric, operational, and environmental characteristics of a traffic facility determine the informational needs and, thus, the efficiency of night visual communications.

Informational needs identified by the study teams were classified according to geometric, operational, or environmental conditions producing them. Those conditions and accident history were used as the parameters for traffic facility classification. The adequacy of the classification scheme is dependent on the reliability of the team studies, accident data in the literature, and professional judgment.

3. Roadway lighting is warranted by the informational needs on a traffic facility.

The classification process presented in this research is a method of determining visual information needs on a given traffic facility and, thus, of justifying (warrants) for lighting. The process is a definite quantification of the conditions producing informational needs as well as accident history. Minimum warranting conditions are those for average conditions on a given functional classification. It is possible for the minimum conditions to be changed, depending on the basic philosophy of the agency using the procedure. The true effect of setting the minimum conditions is not critical if a priority procedure is followed in conjunction with the warrants. If that is done, those facilities with greatest needs will be scheduled for implementation first and will receive the available funds.

4. The design level of intensity depends on the magnitude of the informational needs on a given facility.

A positive method for determining design intensity has been suggested. It is quantitatively related to the magnitude of warranting conditions and, thus, to visual information needs. It is not directly related to any specific visual task problem. A vision model that accounts for every conceivable modifier in any given visual task problem would be desirable. Also desirable would be having available pavement reflectance data for all pavement types and having the lighting designer control pavement reflectance for the design life of the lighting system. Such a visionary model is not practical or possible now. There is no design-oriented method for obtaining pavement reflectance data, and if there were current pavement maintenance practices (e.g., overlay) would destroy its utility. Thus, the procedure presented here is a realistic and rational approach.

5. Cost effectiveness should be used to evaluate alternative lighting designs.

Cost effectiveness is the only method of economic analysis amenable to roadway lighting. All other methods use monetary evaluations of effectiveness or benefits, and not all lighting effectiveness can be measured in dollar terms. For example, what is the value of informational input? What is the value of driver comfort? This paper suggests that effectiveness can be measured in terms of supplying informational needs. As more needs are provided, the effectiveness of lighting increases.

6. Priorities for fixed lighting installations are established on the basis of need related to cost.

Information needs, reflected in warranting conditions, serve as the effectiveness measure in priority determination. The priority model presented will favor those facilities with high warranting conditions that can be lighted most economically.

7. Full success of the total design process depends on its flexibility for growth, change, correction, or modification that may result from field implementation and evaluation and from subsequent research.

The process has a flexibility for growth, change, correction, or modification. Every effort should be made by practitioners and researchers to contribute to its success. The total design process should be subjected to trial implementation and evaluation by agencies responsible for roadway lighting practices. The necessary revisions should be made, and then the process should be incorporated into practice. It is recognized that setting policies and procedures for design and administrative purposes is not within the province of research. However, it is believed that the current design guidelines could be revised to incorporate the features of the total design process.

REFERENCES

1. Adrian, W., and Schreuder, D. A. A Simple Method for the Appraisal of Glare in Street Lighting. Lighting Research and Technology, Vol. 2, No. 2, 1970, pp. 61-73.
2. American National Standard Practice for Roadway Lighting. Illuminating Engineering Society, American National Standards Association, unpublished, 1971.
3. An Informational Guide for Roadway Lighting. AASHO, Washington, D.C., 1969.
4. Blackwell, R. H., Schwab, R. N., and Pritchard, B. S. Visibility and Illumination Variables in Roadway Visual Tasks. Illuminating Engineering, May 1964.
5. Box, P. C. Effect of Highway Lighting on Night Capacity. Traffic Engineering, Vol. 28, No. 4, Jan. 1958, pp. 9-15, 23.
6. Box, P. C. Relationship Between Illumination and Freeway Accidents. Illuminating Engineering Research Institute, New York, April 1970.
7. Bryan, W. E., and Hofstetter, H. W. Vision of Automobile Drivers. Jour. American Optometric Association, Vol. 29, 1958.
8. Cassel, A., and Medville, D. Economic Study of Roadway lighting. NCHRP Rept. 20, 1966.
9. deBoer, J. B., ed. Public Lighting. Philips Technical Laboratory, Eindhoven, The Netherlands, 1967, pp. 31-59.
10. Down Go Accidents and Robberies. The American City, Vol. 80, No. 11, Nov. 1965, p. 116.
11. Effects of Illumination on Operating Characteristics of Freeways. NCHRP Rept. 60, 1968.
12. Fowle, A. W., and Kaercher, R. L. Roadway Brightness and Illumination as Related to Luminaire Distributions. Illuminating Engineering, Vol. 54, No. 4, April 1961, pp. 279-290.
13. Gordon, D. A. Experimental Isolation of the Driver's Visual Input. Highway Research Record 122, 1966, pp. 19-34.
14. International Recommendations for the Lighting of Public Thoroughfares. CIE, Publ. 12(E-3.3.1), 1965.
15. Ketvirtis, A. Highway Lighting Engineering. Foundation of Canada Engineering Corp., Ltd., Toronto, 1967.
16. King, G. F., and Lunenfeld, H. Development of Information Requirements and Transmission Techniques for Highway Users. NCHRP Rept. 123, 1971.
17. McFarland, W. F., and Walton, N. E. Economic and Accident Potential Analysis of Roadway Lighting Alternatives. Highway Research Record 377, 1971, pp. 92-102.
18. Rockwell, T. H., Ernst, R. L., and Rulon, M. J. Research on Visual Requirements in Night Driving. NCHRP Rept. 99, 1970.

19. Rowan, N. J., and Walton, N. E. Roadway Illumination Systems. Texas Transportation Institute, College Station, Res. Rept. 137-3F, May 1972.
20. Rowan, N. J., Woods, D. L., and Johnson, J. H. A Summary Report of the Significant Points From the Diagnostic Field Studies. Texas Transportation Institute, College Station, Res. Rept. 606-4, Sept. 1970.
21. Schmidt, I. Visual Considerations of Man, the Vehicle, and the Highway: Part I. SAE, Publ. SP-279, March 1966.
22. Senders, J. W. The Attentional Demand of Automobile Driving. Bolt, Baranek and Newman, Inc., Boston, Rept. 1482, March 1967.
23. Traffic Control and Roadway Elements—Their Relationship to Highway Safety. Highway Users Federation for Safety and Mobility, 1971, Ch. 1-12, rev.
24. Walton, N. E., and Rowan, N. J. High-Mast Lighting. Texas Transportation Institute, College Station, Res. Rept. 75-12, 1969.
25. Walton, N. E., and Rowan, N. J. Supplementary Studies in Roadway Lighting. Texas Transportation Institute, College Station, Res. Rept. 75-13, 1969.
26. Woods, D. L., and Rowan, N. J. Diagnostic Studies of Highway Visual Communication Systems. Texas Transportation Institute, College Station, Res. Rept 606-9F, April 1972.
27. Walton, N. E. Investigation of a Rational Approach to Design of Fixed Roadway Lighting. Texas A&M Univ., College Station, dissertation, Aug. 1972.

DISCUSSION

J. Stuart Franklin, Hendersonville, North Carolina

For the first time, the roadway lighting design process is formally considered from a systems standpoint and is based on recognized visual information needs of the driver. That is good and represents a major step forward.

As with any first attempt, however, controversy will arise over how the rating and weighting systems were derived. Perhaps the authors should have gone into detail in that area, for example, the rational and mathematical analysis used, the number of people participating in those decisions, and information on their backgrounds, training, and especially their visual capabilities. In this area, several questions come to mind:

1. There is no mention of weather factors such as rain, snow, or fog. Why were those important environmental factors excluded?
2. With reference to "pavement condition multipliers," no mention is made of wet pavements being darker than dry pavements or of rough, good skid-resistant pavements being darker than smooth, poor skid-resistant pavements. Also, under heavy traffic conditions and in snow areas the pavement may hardly be visible to most drivers. Can those considerations be included in future revisions of this design procedure?
3. I wonder whether the statement is true that "quality of light can be controlled through existing standard practice luminaire designation." This appears to be an area that needs to be included in an overall design process but is not. Individual municipal governments are beginning to set their own standards. That practice can lead only to confusion in the future.

A feature that this paper, which is promoting a new approach, should have included is one or two practical examples. For example, a state highway department should have applied this method, compared it with the standard day-to-day approach, and reported whether the same or different results were obtained and what the advantages and disadvantages are of applying this approach to real-world situations. Perhaps that could be the subject of some 1974 papers.

A departure from present practice is in recommending "minimum" illumination in the region 30 ft out from the pavement. Perhaps the authors could comment on the uniformity they expect in that region and whether those conditions can be obtained from existing luminaires.

Quality in lighting (as in everything else) costs money. In analyzing Eq. 3, the cost-effectiveness priority model, I seem to find that the priority index increases with the number of warranting points, the number of vehicles, and the number of miles and decreases with increased lighting cost. Low-cost, poor-quality jobs will always have a high priority index. That, of course, refers to my question 3 above. Will the authors expand on how "quality-of-lighting" factors can be better included in their mathematical model?

Richard E. Stark, Illinois Department of Transportation

A total design process must be based on adequate research. Basic research establishes the relation between the environment and the motorists or pedestrians.

Psychophysiological studies must be made to determine the total visual needs in a variety of environments. Those visual needs can be divided into static and dynamic scenes. Each one must be analyzed to determine the optimal lighting design required to satisfy the needs. It does not appear at this point that the required research exists although parts of the visual relation between the driver and his environment have been defined.

Past procedures have been to determine lighting levels in terms of overall environment and operational characteristics of the roadway. The purpose here is to provide a basic economic criterion for installation of systems. The lighting engineer has always been responsible for adjusting to geometric and operational influences on a unit by unit basis. For example, it may be determined that a freeway is to be lighted to a level of 0.6 ft-c. That figure establishes nothing more than a gross economic overview of the system; it says very little about the type of system or quality. Systems could range from one with 150-ft towers at long spacing to one of continuous luminaires mounted a few feet from the roadway.

Specifying a uniformity ratio of 3 to 1 does begin to help; but, even using that ratio, one can obtain a variety of designs, some of which are not very uniform.

To present, in addition, a criterion of maximum to minimum of 6 to 1 further qualifies the type of design but does not automatically provide better visibility. In fact, in some instances the design may be hindered by requiring this ratio.

At the present time, the most important asset an illumination engineer has in designing a system is experience. He must be able to adequately illuminate those objects that are important to the motorist. Sufficient illumination quantity and quality must be provided not only on pavement surfaces but also at locations of specific geometric configurations in such a way as to reveal their presence to the night motorist.

A system can meet all of the criteria set forth in this paper and still hide the areas that are critical to the driver's visual needs. I am referring, of course, to the geometry of the lighting design. Because the 5,000- to 10,000-ft-c level of daylight is not available to reveal all objects by surface detail, lighting engineers must concentrate on fixture placement and distribution patterns to reveal those areas. Examples of those types of configurations are ramp entrances and exits, gore areas, guardrail installations on horizontal and vertical curves, intersections, pedestrian crossings, fixed objects adjacent to the pavement, and numerous other physical features. In addition, there are the intermittent vehicle and pedestrian in the dynamic visual scene. The criteria to be used in placing fixtures and selecting distribution patterns to properly illuminate those features have to my knowledge not been documented.

Regarding the matter of warrants, several factors must be considered. Many of them have been confirmed in this presentation, but I would like to suggest two others. One is driver comfort, which appears to have no weighting factor. It is extremely difficult to measure as are many of the items included in the environment portion of the warrants. We should recognize, however, that an irritated driver is more of a potential accident candidate.

Another factor is the recognition of pedestrians as traffic. Their lighting needs should certainly be considered. It is not always true that a lighting system properly designed for motorists is also adequate for pedestrians. Pedestrain problems with glare and parkway lighting must be considered.

An area that appears to have diminishing importance in this report is traffic volume. I believe that traffic volume is still very important despite the geometric conditions. A poor geometric situation with extremely low volumes may not warrant lighting because the number of events and conflicts are of little significance. On the other hand, a roadway as nearly perfect as possible can still have events that are related not to geometrics but to volume. As volume increases, events such as vehicle breakdowns, multiple vehicle accidents, debris falling from trailers and trucks, and erratic pedestrian occurrences begin to increase and occur on a regular basis. Higher volume usually means higher numbers of pedestrians: motorists who leave their vehicles because of disabilities and accidents and an occasional hitchhiker. On the Chicago expressway system in one year, approximately half of the fatalities were pedestrians (38). My thought is that volume should be included with the operational factors. Also, should not pedestrian traffic be included in Table 1 under controlled-access facilities?

The use of the weighted system of warranting lighting on a new freeway facility would be very difficult. Because no accident experience is possible, no lighting would be provided. In designing new freeways, highway designers today usually attempt to eliminate all known problems of the past. So, comparison with existing installations is difficult. Operational factors and environmental conditions are also difficult to assess before the roadway is actually constructed. Many of those features are actually generated by the new facilities. Shopping centers, housing developments, frontage roads, industrial sites, and parks usually spring up when transportation needs are met.

Another area relative to the presentation is the matter of crime and its relation to fixed lighting. Should crime rate be included in the factors for freeway lighting? A disabled motorist is a potential victim. How does one arrive at a weighting factor for crime?

A pavement multiplier to consider the different reflectance factors of the pavements has been included in this report. As previous reports have shown, pavement reflectance is extremely difficult to determine and use in lighting calculations. The reflectance factor can change because of roadway wear or staining during the life of the pavement. How can that be predetermined?

The authors state that there are elements of the visual environment that often can be made adequately visible by vehicle headlights. Some qualification ought to be made here in terms of the inadequacies of headlights. Headlights as well as the suspension system of the vehicle must be properly maintained. Even with new lamps and proper alignment, vehicle speeds of more than 50 mph leave the motorist little or no time to react to objects as they become visible. Finch has estimated that a third to a half of all vehicle head lamps are misaimed.

The matter of cost effectiveness is somewhat confusing. Each design is optimized, but the best design is selected based on the judgment of the designer. That design may have the best illumination but have a higher cost, in which case it will be low on the priority index. A poor design may have a high priority. On the other hand, one may be able to increase the value of F design level at a higher rate than the annual cost, in which case a higher priority will be given to jobs with higher design levels. Some designs can be doubled in level for less than twice the increase in cost. In summary, cost effectiveness is a good technique to provide decision-making information, but good judgment is still required to select quality designs at reasonable costs.

In the introduction to the paper, the authors point out that the current practice of roadway lighting is specified in terms of lighting a roadway surface rather than providing an environment suitable to the driver. The authors are quite accurate in that statement, and I believe there is much evidence of this in existing installations. They go on to say that ideally the total design process should be based on requirements for a suitable visual environment. It is quite apparent that the authors have identified many of the visual needs in a suitable environment. They conclude that the quantity and the degree of needs should determine quantity of light. My question is, Is not this final quantity specified in broad terms of lighting a roadway's surface? What relation does that have to the supply of visual information to the driver?

A. Ketvirtis, Foundation of Canada Engineering Corporation, Ltd., Toronto

Walton and Rowan attempted to present "a total design process for roadway lighting" based on drivers' information needs. That is a difficult and ambitious task indeed. The authors deserve credit for such a courageous undertaking, particularly when the limited frame of a conference paper imposes serious restrictions on the analysis of such a complicated subject in more detail.

The authors first review the total design process and the present practice in North America and then offer their alternative methods of improvement. The paper treats warrants as part of the lighting design. The material included is interesting and, in many ways, is new, at least the application to the illumination field.

After studying the contents of the paper, I would like to make several observations:

1. In the introduction, the authors state that the objective of their paper is to propose a "total design process." My understanding of "totality" in design is when most of the major aspects of procedure are included in the considerations. An illumination system, as the authors agree, "involves a complex interrelation" among many other factors, such as information needs, light application techniques, roadway geometry, paving materials, consideration of traffic conditions (density, speed, and peaking), accommodation of the driver's psychophysiological limitations, visual perception, acuity, visual field, lighting system geometrics, and safety requirements. Although the authors analyze many basic aspects, many other areas are left out. Therefore, the paper could have been of greater value had the title been more specific.

2. The authors also state in the introduction that "there is no comprehensive process for roadway lighting design that adequately relates to the visual needs of the driver." Research by de Boer, Dunbar, Schreuder, Adrian, and many others deals very specifically with luminous intensities, contrasts, glare, and other aspects of the driver's needs to perform his driving task safely and efficiently. Much of this information is included in the publication edited by de Boer (9). CIE recommendations for motorway lighting issued in 1971 are based on such research findings.

3. The authors present a formula for correcting illumination levels suggested in the IES recommendations. Unfortunately, the levels of illumination proposed by IES have no scientific value because they are based on a purely empirical agreement and are not related to eye performance. Even if the correction factor E, suggested by the authors, reflects the true assessment of difficulty, the basic value (I) used in the equation remains empirical. Such a situation cannot produce scientifically forceful results.

In conclusion, the paper contains a considerable amount of valuable information, and the authors should be credited for their contribution to the advancement of illumination technology.

AUTHORS' CLOSURE

The authors express appreciation to the discussants and thank them for their compliments and constructive criticisms. We are particularly pleased that they find merit in the total design process presented.

Before specific responses to comments are made, several points are noted. The authors are firmly convinced that roadway lighting improves highway safety. We feel that it is important to establish practical and useful warrants, guidelines, and priorities. What we are really trying to say is that elephants roam the streets (warrants, guidelines, and priorities) while we stomp ants (0.6 versus 1.0 ft-c or luminance versus illumination). This paper is concerned not so much with ants as with elephants. We hope that we have at least hit the elephants and attracted attention to them.

In response to Franklin's first general comment regarding the rating and weighting system, brevity required that much detail be deleted in the paper. In short, the various geometric, operational, and environmental factors were determined at 8 study sites in Dallas and Atlanta by the diagnostic team study approach. The team in each location consisted of 4 professionals and 4 nonprofessionals. The professionals represented the fields of design, lighting, traffic, and psychology. The nonprofessionals represented the driving public and consisted of 2 males and 2 females. Their visual capabilities were not measured in any way.

The ratings and weightings of the factors were established by a professional research team of 6 people representing traffic characteristics, traffic operations, geometric design, illumination design, economics, and human factors. The professional team established the relative importance of the characteristics by using data available in the literature and a broad base of professional expertise and judgments.

Franklin also asks about the deletion of weather factors, wet versus dry pavements, and quality of light. Those elements could be integrated into the overall design process for specific local areas. With regard to uniformity in the 30-ft region from the pavement edge, that may be specified as it is for the main lanes and achieved with existing equipment.

Franklin's question regarding the cost-effectiveness priority model may also be raised because of the brevity of the report. The low-cost, poor-quality jobs will not have high priority indexes. This is controlled through the selection of the most cost-effective design to be entered into priority competition. To be effective, the design must meet both intensity and uniformity criteria. In addition, a quality criterion in terms of cutoff or some other measure of effectiveness may be included, as may any other desired criterion.

No examples were presented in the paper in interest of time and length of manuscript.

Stark pointed out the absence of appropriate psychophysiological studies. Psychophysiological studies were considered in this research; however, known technology, time, and financial limitations precluded any action. We see, however, this research as providing direction for psychophysiological studies of the future.

We agree with Stark that the most important asset an illumination engineer has in designing a system is experience. His points regarding geometry of the lighting system are well taken and perfectly compatible with the suggested total design process. Those areas are included in the optimization of system design to produce cost-effective results.

Driver comfort is included in the process, for comfort is related to information need. It is also included in terms such as level of advertising lighting and level of service. Driver comfort per se in discrete quantities is not included for the very reason he specifies: How is it measured?

Pedestrian traffic is included for the non-controlled-access facilities. Pedestrian volume is not included as a warranting factor for controlled-access facilities. If it is present, however, pedestrian traffic should have adequate lighting, as Stark suggests.

Stark's interpretation is that traffic volume is of diminishing importance in the paper. Quite the contrary is true. It is included in levels of service, a more meaningful term than volume. It is, however, of lesser importance from a warranting standpoint. It does not serve as the single warrant but is of extreme importance in the establishment of priorities in the attempt to serve the most people possible with limited resources.

We also recognize that pavement reflectance is extremely difficult to determine and use in lighting calculations. That is the reason that a judgmental rating of 1 to 5 has been used for that factor.

We agree with Stark's statement that "cost effectiveness is a good technique to provide decision-making information, but good judgment is still required to select quality designs at reasonable costs." We would want our procedure to be used in that manner.

Ketvirtis' comment regarding totality and paper title is acknowledged. We may have left out some important areas so that the process is less than total, but the title of the paper is unimportant.

Regarding the work by deBoer, Dunbar, Schreuder, Adrian, and others, we agree that their accomplishments are very noteworthy. However, we see little benefit in such minute calculative procedures when no vision model is available or practical; when pavement reflectance data are unobtainable in a design-oriented method; when current pavement maintenance practices would negate such an approach even if data were available; and when most designers in the United States would not accept such procedures. Maybe our wording should have been, "There is no practical or useful process currently available that relates to the visual needs of the driver."

In reply to Ketvirtis' final comment on lighting levels, we simply refer to previous discussions of levels of intensity.

In summary, let us restate our seventh interpretative statement: Full success of the total design process depends on its flexibility for growth, change, correction, or modification that may result from field implementation and evaluation and from subsequent research. Our total design process for roadway lighting has that flexibility.

STUDIES OF TRAFFIC SAFETY BENEFITS OF ROADWAY LIGHTING

Richard E. Stark, Illinois Department of Transportation

Numerous laboratory studies have been conducted to relate illumination levels and driver performance at night. Selected field studies have been made to relate the ability of drivers to recognize certain objects on the roadway under different illumination conditions. The latter studies have normally been of static conditions. The purposes of roadway lighting are to improve driver comfort and efficiency and to reduce accident frequencies. Studies have been made to correlate fixed roadway illumination and accidents, but the findings have not been entirely consistent for several reasons: inadequate sample sizes, lack of quality control on data collection, and inappropriate techniques of analysis. The purpose of this paper is to review some of the studies that have been made and some of the strengths and weaknesses of various study techniques.

•TWO GENERAL types of roadways have been studied: urban surface streets, which may be subdivided into major routes, collector streets, and local streets, and freeways, which may be characterized as urban, suburban, or rural.

Three kinds of accident studies have been performed: accident rates or frequencies on lighted roadways (at any illumination level) and on unlighted roadways of similar characteristics and effects on accident occurrence of different degrees of lighting, including illumination level or uniformity.

Special elements may be considered, such as frequencies of collision with lighting poles at various setback distances or by type of pole, i.e., rigid versus breakaway.

The effects of lighting as related to accidents may be analyzed by 2 general techniques. One is to use before-and-after data from a given segment of roadway. A number of such studies on similar types of roadways may be combined. The second method of comparison is the parallel type. In this analysis, accidents on comparable roadways (except for the lighting variable) are tabulated.

REVIEW OF PRIOR STUDIES

Principal studies of accidents on urban surface streets as related to lighting have been conducted by Seburn (1), Box (2), and De Leuw, Cather and Associates (7). Studies of freeway lighting, principally in urban and suburban areas, have been conducted by Huber and Tracey (3), Johnson and Tamburri (4), Box and Alroth (5), and Yates and Beatty (6).

Accident data may be presented as the percentage of total accidents that occur at night or as the night-day accident ratio, which is the number of accidents at night divided by the number during the day.

Alternate ways are the night accident rate, which is the number of accidents per million vehicle-miles (or per 100 million vehicle-miles) of travel, and the night-day rate ratio, which is the night mileage rate divided by the day mileage rate.

Table 1 gives the routes, methods of comparison, and accident sample sizes used in several major studies. The studies are discussed below.

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Kansas City

Seburn (1) reported results in the early stage of the Kansas City, Missouri, relighting program and used the ratio of day accidents to night accidents on a before-and-after basis. Another characteristic of those studies of major routes was the subclassification by volume groupings. At that time, the American Standard Practice for Roadway Lighting specified illumination level as a function of vehicular volume.

Subsequent studies by Box (2) used volume groupings but employed the percentage of total accidents occurring at night as the study method. His data also were subdivided by different illumination levels in order to determine whether this variable could be related to accident reduction as a result of relighting. A trend was noted, as given in Table 2 (15).

The data given in Table 2 are for 97 miles of streets relighted to conform with the then-recommended illumination levels. A change of 1 percent in accidents at night is equivalent to a 2 percent change in the accident frequency, when the effect of changes in the number of day accidents is also equated. On that basis, the data show that the relighting of major routes in Kansas City reduced overall property damage accidents about 4 percent, injury accidents about 18 percent, and fatal accidents about 28 percent. In 1966 the data were retabulated, based on the illumination levels provided in the relighting (8). Table 3 gives the percentage change for fatal and injury accidents during a 1-year period.

Box also used traffic counts at 122 locations on Kansas City streets to determine the average percentages of vehicle-miles driven at night. He found that total travel at night amounted to 26 percent on major streets and 24 percent on local residential streets. He postulated that, with that percentage of traffic at night, the expected conflicts with pedestrians would be much lower than during the day and that the percentage of pedestrian accidents at night, on properly lighted streets, should not exceed about 25 percent. Results from the Kansas City lighting program, which was initially addressed to the major streets where most night pedestrian accidents were occurring, verified this. By 1951 nearly half of the streets had been relighted. In the 6 years prior to that period, an average of 63 percent of pedestrian fatal accidents occurred at night. From 1951 through 1957, between 25 and 40 percent occurred at night; the average was 30 percent.

The Kansas City accident studies represent a simplified approach to analyzing the relation of lighting and accidents. From these and other studies, authorities have concluded that a serious night-accident problem may be assumed to exist when the ratio of night-day accidents is more than 1.5 times the average ratio for similar locations or sections on the same system of roads and streets (9). That language is part of a standard resulting from the Highway Safety Act of 1966.

Syracuse

The project in Syracuse (7) was planned to determine the type, priority, and amount of roadway lighting needed to reduce the ratio of nighttime to daytime vehicular and pedestrian accidents on the surface street system. A secondary purpose was to evaluate the economic impact on the city of upgrading street lighting to national standards.

The work included functional classification of the street network into major, collector, and local streets in accordance with the then-current edition of the American Standard Practice for Roadway Lighting (10). That work used prior classification planning studies, traffic volume data, and field surveys.

The types of development abutting the major and collector streets were determined from land use maps and field checks. Street widths were measured, and checks were made of the lighting system on a block-by-block basis. Separate sections were set up for each street segment where a change in width, illumination level, or functional classification occurred.

Accident data for 1 year were used, and the night-day accident ratio was computed for each segment. Those segments were then related by type of street and by illumination level. The night-day ratio of accidents was plotted as a function of maintained horizontal footcandles (HFC). From the curves, the optimum points of illumination were selected. In practically every case, worse ratios were produced by low and high illumination levels than by the intermediate level.

These optimum points were used for recommended changes in illumination of the city streets. A value of 1.8 HFC was determined to be the most favorable for major streets in downtown areas and intermediate areas. In outlying areas, a highly significant optimum point was not found, but a value of 0.8 HFC appeared to be appropriate. For collector streets as a group, the lowest accident ratio was found at an illumination level of about 1.0 HFC.

In the Syracuse study, a larger accident sample would have been desirable. Aside from that limitation, the type of approach appears to hold promise for future studies relating illumination levels and accident frequencies.

Connecticut Turnpike

As originally contemplated, a study was to be made of the effect of 3 different illumination levels on the Connecticut Turnpike (3). At the time of the study, the turnpike was lighted to a maintained level of approximately 0.6 HFC. A test section of 4.1 miles had illumination lowered to approximately 0.2 HFC. A second revision in the section, raising illumination to a level of 1.5 or 2.0 HFC, was not undertaken.

The lowered illumination in the test section was maintained for a 9-month period, during which only 36 night accidents occurred. Despite the fact that excellent control data were available from adjacent segments of the highway, the very small sample of night accidents in the test section did not produce any evidence that the illumination change had any effect on accident frequency.

Table 4 gives the accident data. In the test section, there was an apparent increase in the accident rate per million vehicle-miles. However, much larger increases were found in the control sections.

A more appropriate way of analyzing the data might be to use the night-day ratio of accident rates. On that basis, one could postulate an apparent improvement as a result of the lowered ratio during the test. However, the east control section showed a tremendous change in the night-day ratio, even though no change was made in the lighting. In the west section, where the sample of night accidents was more than 5 times greater during the test period and more than 3 times greater than that of the east section, little variation occurred in the night-day ratio. A more convincing demonstration of the importance of accident sample size could hardly be found.

The Connecticut Turnpike study demonstrates the value in calculating vehicle-miles of travel by day and by night and computing the night-day ratio of rates from those data.

Based on MVM data given in Table 4, about 27 percent of turnpike travel occurs at night. As will subsequently be shown, it is practical to calculate the ratio without MVM data if the percentage of night travel is known or can be estimated from other studies of comparable facilities.

Los Angeles

The Los Angeles study (4) was based on data on nonilluminated and illuminated freeways in the Los Angeles area. The study used the percentage of accidents at night and also the night-day accident ratio. The California researchers included dawn and dusk as part of night; with this questionable measure, they found approximately 30 percent of travel to occur during the night.

Maintaining that definition and recalculating the figures from the California study to relate them to the more generally accepted night-day ratio of accident rates per million vehicle-miles, we can determine a ratio of 1.58:1 for illuminated freeways and 1.85:1 for nonilluminated freeways.

The California work had an excellent data base. Although the researchers did not conclude that the differences in the day and night accident rate ratios were significant, the principles of their study are valid.

Another interesting technique they employed was to compare accident rates during the period of 5 to 7 p.m. in June, when it is daylight, with those during the same time period in December, when it is dark. An improved accident record was found on illuminated freeways as compared with the ones having no lighting. However, the sample sizes were quite small (on the lighted freeways during the 2-hour period, 34 accidents

Table 1. Characteristics of major accident-illumination studies.

Characteristic	Kansas City	Connecticut Turnpike	Los Angeles	IERI	Urban Interstate Highways	Syracuse
Types of routes						
Freeways		x	x	x	x	
Major routes	x					x
Collector streets						x
Methods of comparison						
Before-and-after	x	x		x		
Parallel type, lighted versus unlighted			x	x	x	x
Illumination level	x	x	x	x	x	x
Uniformity			x	x		x
Mehods of study						
Percentage of accidents at night	x					
Night-day ratio	x		x			x
VMT rates for selected hours					x	
Total night accidents		x		x		
Night-day ratio rates			x	x		
Number of accidents studied	8,700	2,640	17,170	21,400	Unknown	7,500

Table 2. Change in proportion of accidents at night on relighted streets in Kansas City.

			Before			After		
				Night			Night	
Traffic	Vehicles per Hour	Accident Type	Day	Number	Percent	Day	Number	Percent
Light	150 to 500	Property damage	324	201	40	365	200	35
		Injury	47	45	49	57	34	37
		Fatality	3	3	50	2	1	33
Medium	500 to 1,200	Property damage	1,411	828	37	1,443	789	35
		Injury	172	210	55	152	135	47
		Fatality	10	17	63	6	5	45
Heavy	1,200 to 2,400	Property damage	547	323	37	672	340	34
		Injury	75	96	56	59	51	46
		Fatality	3	8	73	2	4	67
Total		Property damage	2,282	1,352	37	2,480	1,329	35
		Injury	294	351	54	268	220	45
		Fatality	16	28	64	10	10	50

Table 3. Fatal and injury accidents after major route relighting in Kansas City.

				Night Accidents					
		Day Accidents		Before		After		Change	
Lighting Level (HFC)	Route Miles	Before	After	Number	Percent	Number	Percent	Number	Percent
0.2 to 0.39	38.7	80	99	67	46	86	46	+19	+28
0.4 to 0.59	40.8	126	99	173	58	82	45	-91	-52
0.6 to 0.79	7.2	45	23	43	49	23	50	-20	-47
0.8 to 0.89	5.9	31	36	72	70	28	44	-44	-61

Table 4. Accident rates on Connecticut Turnpike.

			Night			Day			
Section	Route Miles	Time	Accidents	Million Vehicle-Miles	Rate	Accidents	Million Vehicle-Miles	Rate	Night-Day Ratio Rate
West	27.6	Before	357	253	1.4	556	858	0.65	2.17
		During	204	97.3	2.09	304	331	0.91	2.28
Test	4.1	Before	79	43.7	1.80	167	179.7	0.93	1.93
		During	36	16.5	2.18	95	68.3	1.39	1.57
East	15.9	Before	82	83.8	0.98	263	346	0.76	1.30
		During	60	31.8	1.89	95	131.8	0.72	2.62

occurred in June and 41 in December). The technique may offer some promise, however, for application during a period of several years in areas having significant mileages of illuminated and of nonilluminated freeways.

IERI

A project sponsored by the Illuminating Engineering Research Institute (5) involved more than 200 miles of lighted and unlighted freeways; more than half the mileage was in urban or suburban areas. The study purpose was to relate night-day ratios of accident rates to varying illumination levels and uniformities. The study also provided before-and-after data for 2 freeway sections and data for both illuminated and nonilluminated sections of another freeway.

On many freeway sections, continuous hourly traffic data were available for 12-month periods. From light-meter readings at dusk and dawn, the researchers concluded that darkness (when the natural light level is only a few footcandles in value) ends about 15 min before sunrise and begins 15 min after sunset. Those data and traffic volumes, including interpolation of volumes during the dusk and dawn hours, were used to calculate night travel. Findings from Toronto, Chicago, Dallas, Atlanta, Denver, and Phoenix (including areas without daylight saving time) were that an average of 25 percent of annual night volumes can be expected on freeways in urban, suburban, and rural locations.

One of the aspects of the IERI study was the care taken in accident data tabulation. The researchers worked directly from accident reports in police files or from duplicate copies in files of traffic engineers in the various cities. The researchers separated the accidents occurring on ramps from those that occurred on the main line, at ramp entrances to the freeway, or at ramp exits from the freeway. They screened out accidents solely involving ramp connections to service streets because the illumination of the latter points is not necessarily representative of a given freeway illumination design. Furthermore, because of the possibilities of misfiling and miscoding, the most accurate method of tabulating accident data is to work from the accident reports themselves. This method also allowed comparison with outputs from computer systems. Errors ranging from 19 to 62 percent were found when data from the direct reports were compared with the printouts. Such differences in values could evidently mask lighting effects.

The IERI study found that lighted freeways had a night-day ratio of accident rates equal to 1.43. The unlighted freeway ratio average was 2.37. The net effect of lighting an urban freeway was concluded to be a 40 percent average reduction in night accidents. That is equivalent to an overall accident reduction of 18 percent (considering total day and night accidents). The apparent effect of freeway lighting on fatal and injury accidents represents a 52 percent reduction in night accidents.

The findings with respect to an "optimum" illumination level were similar to those of the Syracuse urban surface street study. The lowest ratio of night-day accident rates was found at a maintained illumination level of approximately 0.5 HFC. Based on the maintenance factors found at the various study sites, that value is equivalent to an initial illumination design of about 1.0 HFC.

In comparisons of lighted and unlighted sections of the same freeway and of before-and-after studies, the lighted freeway sections were found to have lower average ratios of night-day accident rates.

The freeway sections studied by IERI researchers had a very broad range of accident rates. Daytime rates varied from 0.39 to 9.24 accidents/MVM. Night rates ranged from 0.62 to 9.98 accidents/MVM. Such variations are typical of actual field conditions. To meaningfully study the effects of an element such as lighting, the researchers concluded that each section must be tested against itself. That cannot be accomplished by comparing night MVM accident rates among different freeways, but it can be done by calculating the ratio of night-day rates separately for each section and then comparing the ratios.

Urban Interstate Highways

A lighting study was performed as part of the Interstate System Accident Research, Study II (6). Data were furnished by various state highway agencies. The accident data were tabulated on an hourly basis; however, a tabulation of actual traffic volumes during only hours of darkness was not obtained. Presumably because of this, the research on night accident rates covered a period of consistent darkness (9 p.m. to 4 a.m.) for which traffic data were available.

The lighting portion of the Interstate accident studies was confined to the main-line freeway sections between interchanges in urban areas. The study concluded that "there is no discernible relationship between lighting intensity and accident rate on 2-lane or 3-lane main-line units." (This means 4-lane or 6-lane freeways.)

Although the data tabulation procedures for the Interstate study may be adequate for analysis of geometric design elements, some question can be raised as to their application to studies of lighting. To make a direct check, the Illinois Department of Transportation conducted a special study of accidents on several sections of Chicago freeways. Those sections duplicated ones that were analyzed in the IERI study, except that the Interstate Accident Study Procedure Manual was employed. To eliminate the data processing errors, the researchers worked directly from the same highway patrol accident reports on file with the department that were used in the IERI research.

Comparison of data from the 2 methods shows that only 60 percent of the total actual night accidents occurred from 9 p.m. to 4 a.m. Evidently, a reduction of that magnitude in the data base of the samples would have an adverse effect on statistical significance.

A comparison was also made of accidents tabulated on the main-line sections between interchanges, as contrasted with those in the interchange areas. In the IERI project, traffic engineers skilled in accident tabulation and analysis screened the accident reports. In the Illinois studies, lighting technicians were given instruction in reading accident reports, but they performed the actual tabulation without supervision of a traffic engineer. Differences would thus be expected in findings from the same data files. The differences ranged from 4 to 30 percent; the average was 13 percent. The traffic engineers found that a higher proportion (64 percent) of the accidents on the study section occurred on the main-line sections.

The Illinois study also compared the accident rate per million vehicle-miles at night and the 24-hour rate. In 2 sections on which before-and-after accident studies were performed, the differences found between the 2 methods ranged from 0 to 42 percent; the average was 16 percent. At one location, the change in the ratio of accident rates was 41 percent by the Interstate accident procedure and only 16 percent by the IERI procedure. On another section, the change in the ratio was 12 percent by the Interstate procedure and 33 percent by the IERI procedure.

A comparison of night accident rate computations per million vehicle-miles agreed on only 1 section. Differences as high as 33 percent were found in other sections; the average variation was 15 percent.

Those differences suggest that studies of accident effects, especially as related to items such as lighting, should be performed by experienced accident analysts. Furthermore, the use of straight rates per MVM in the basic, original Urban Interstate Highway Study technique, rather than the ratio of rates, runs head-on into the problem of widely varying accident rates due to traffic congestion and other elements not associated directly with lighting.

GENERAL DATA REQUIREMENTS FOR LIGHTING STUDIES

Accident Studies

The problems encountered and the successes achieved in various studies suggest that certain accident-tabulation factors are important. One aspect involves the location of the accident. That is needed to identify whether the collision actually occurred on the route under study or whether it involved a cross route having little or no relation to the basic analysis. The accident locations are also important to allow the subdividing of routes into sections having specific traffic or illumination characteristics.

A second element of accident tabulation concerns the date. Specific periods are sometimes needed because of partial-year periods involved in before-and-after analysis or to avoid periods of traffic disruption due to maintenance or reconstruction.

With respect to time-of-day tabulation, a simple "night" or "day" is usually sufficient. However, about 5 percent of the accidents may be found to occur in a dusk or dawn period. If those accidents are to be classified as either day or night, the time of accident is needed to the nearest 5 min. If hourly comparisons are to be made (as in the California studies), then the accident tabulation can be within clock hours.

Traffic Volumes

Box has shown that, if the percentage of traffic at night is known, it is unnecessary to secure vehicle mileage data in order to calculate the night-day ratio of accident rates on a mileage basis (5). The ratio is given by the following equation:

$$R = \frac{A_n (1 - P)}{A_d P}$$

where

R = ratio of night-day accident rate as a function of exposure,
A_n = number of night accidents,
A_d = number of day accidents, and
P = percentage of travel at night.

The findings on percentage of travel at night on urban surface streets in Kansas City and on freeways (Connecticut Turnpike plus the IERI study sites) are generally consistent. In another study on multilane major routes, Billion and Parson also found 25 percent of traffic mileage to occur at night (11). A study by Carroll, Carlson, and McDole on driving exposure of 7,145 persons throughout the country included information on day and night vehicle-miles (12). Interpolation of the data showed the calculated average percentage of travel at night to be 23 percent.

On the basis of those 5 studies, the application of a rounded value of 25 percent for night travel in urban areas (at least) appears warranted.

If it is desired to check or confirm the percentage of actual night traffic at a given location, hourly tabulations of volume are needed for a full 365 days. Those data are customarily taken from automatic recording stations along freeways. They should include the volume in both directions of travel. The calculation method, as reviewed in the IERI study, is as follows:

> The "dark" percentage of volume is separately calculated for the morning and evening dawn and dusk hour in which the threshold lighting condition (15 minutes before sunrise and 15 minutes after sunset) is reached. These percentages are applied as factors to interpolate volume during these two hours.
>
> The factored night volumes are added to the volume during the remaining hours of night traffic to obtain the total night volume of traffic. This value is then subtracted from the 24 hour total to secure the volume during the daylight hours. This procedure is repeated for each day of a full year, utilizing local sunrise/sunset tables and correcting as required for daylight saving time.

Selection of Study Sections

Each section of route should have relative stability during the entire study period. This includes no major change in traffic volumes, physical features, abutting land use, or illumination.

Reliable and accessible accident records are important, and their availability should be ascertained with respect to breakouts to conform with the selected study sections. Similarly, if traffic volume calculations are to be made, accessibility of counts must be verified.

If variations in illumination are to be compared, they should be considered when field measurements are taken of the existing illumination. This can be done in almost any conditions. In the IERI study, illumination was measured on a point-by-point grid method on freeways having as many as 10 lanes and under live traffic conditions. They were generally taken between 2 and 4 a.m.

Study Period

To secure comparable data requires that the seasons be similar. Data from the given months of one year must be compared with data from the same months of another year in most types of studies. An exception is the peak-hour winter versus summer study done in California.

In before-and-after studies, a sufficiently large total number of accidents must be tabulated to reach statistical significance. One measure of this could be the employment of Poisson and chi-square curves as given by Michaels (13). The Poisson curve is recommended by Michaels for use to minimize the chance of calling a reduction not significant when it actually is. At the other end of the scale, the chi-square curve is used to minimize the chance of calling a reduction significant when it actually is not. To illustrate the application of those curves, two hypothetical findings, based on before-and-after accident studies, may be considered. In the case of illumination analysis, it would be appropriate to use only the night accidents. If, for example, 40 accidents occurred at night with a given condition of lighting, a reduction of 25 percent (30 accidents in the after period) would be essential to justify a conclusion that an actual reduction and not chance had taken place. However, a reduction of as much as 40 percent (24 accidents in the after period) would be needed to reach a high level of statistical significance.

By comparison, a sample of 100 night accidents in the before period would require a reduction of only 18 percent to achieve probable significance, and a reduction of not more than 25 percent would be required to meet the more stringent chi-square test. If 200 accidents are involved in the before night sample, then a reduction of only 13 to 19 percent would be significant.

There is no such thing as a statistical guarantee of significance. The extreme variabilities in accident occurrence produced by chance alone may well hide the benefits of an improvement. Conversely, a chance reduction in accidents can cause an unwary researcher to conclude that he has improved a situation when, in fact, his changes have produced no meaningful results. The development of well-controlled accident analysis techniques is currently the subject of an NCHRP project (14). Meanwhile, the application of simple techniques such as that presented by Michaels, coupled with common sense and care in data tabulation, will greatly aid the researcher.

REFERENCES

1. Seburn, T. J. Kansas City's New Lighting Begins Saving Lives. The American City, July 1948.
2. Box, P. C. Relighting Kansas City, Missouri. The American City, March, April, May, and June 1956.
3. Huber, M. J., and Tracy, J. L. Effect of Illumination on Operational Characteristics of Freeways. NCHRP Rept. 60, 1966, Pts. 1 and 5.
4. Johnson, R. T., and Tamburri, T. N. Continuous Freeway Illumination. California Division of Highways, May 1965.
5. Box, P. C. Relationship Between Illumination and Freeway Accidents. Illuminating Engineering, May-June 1971.
6. Yates, J. G., and Beatty, R. L. Relationship Between Lighting and Accident Experience Between Interchanges. Highway Research Record 312, 1970, pp. 85-92.
7. Determination of Priorities for Upgrading Street Lighting in Syracuse, New York. De Leuw, Cather and Associates, Nov. 1970.
8. Box, P. C. Public Lighting Needs. Illuminating Engineering, Sept. 1966.
9. Sielski, M. C. Relationship of Roadway Lighting and Traffic Accidents. HRB Spec. Rept. 93, 1967, pp. 172-177.
10. American Standard Practice for Roadway Lighting. American Standards Association, 1963.

11. Billion, B. E., and Parson, N. C. Median Accident Study—Long Island, New York. HRB Bull. 308, 1962, pp. 64-79.
12. Carroll, P. S., Carlson, W. L., and McDole, T. L. Identifying Unique Driving-Exposure Classifications. HIT LAB reports, Sept. 1971.
13. Michaels, R. M. Simple Techniques for Determining the Significance of Accident-Reducing Measures. Public Roads, Oct. 1959.
14. Methods for Evaluating Highway Safety Improvements. NCHRP Proj. 17-2.
15. Seburn, T. J. Material presented at Nat. Tech. Conf. of Illuminating Eng. Soc., Aug. 1951.

LOW-CONTRAST VISION UNDER MESOPIC AND PHOTOPIC ILLUMINATION

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The objective of this research was to obtain normative data for 3 measures of visual ability under simulated night-driving luminance (mesopic) and ordinary lighting (photopic) conditions, to compare the performance of different age groups, and to compare results with those of a previous study. A total of 371 subjects aged 16 to over 60 were given the Titmus standard acuity test and a Titmus low-contrast test at photopic (34 ft-L) and mesopic (0.4 ft-L) background luminance, the latter simulating night-driving conditions. They were also given the Allen night vision performance test with a 10 percent contrast target at 10 and 0.2 ft-L. Comparisons were made with a previous study in which the NVPT target was 50 to 60 percent. Average scores (thresholds) were higher (poorer) on the Allen test with the 10 percent contrast target than with the 50 to 60 percent, but lower contrast targets were seen on the low-contrast Titmus test. The results seem to indicate that the Allen test with a 10 percent contrast target measured ability to see low-contrast targets against glare in both photopic and mesopic luminance and the Titmus low-contrast test measured low-contrast vision of a different type. Average low-contrast visual discrimination decreased with age. However, some subjects in all age groups exhibited poorer visual performance than most of their own and other age groups, and performance by most older subjects was as good as that of a large proportion of younger subjects.

•VISION of drivers under night-driving conditions is a problem that has concerned a number of investigators. Night driving often presents drivers with difficult conditions of vision because of low illumination and because of low-contrast targets on the highway. For example, pedestrians' clothing, vehicles, or other objects may be of such texture and color that they present relatively little contrast with the background. This problem is of special importance because visibility distances at night are all too limited for present-day driving speeds even under the best seeing conditions.

Low-contrast seeing tasks in daylight driving also may require similar visual discrimination, e.g., seeing one or more vehicles ahead in a snowstorm, especially when the vehicles are overtaken on a snowy road.

A key question is whether low-contrast seeing is mainly a problem for people in older age groups only, as some studies suggest, or whether some drivers in all age groups may show difficulty with low-contrast vision. Normative data are needed to answer this and related questions.

OBJECTIVES OF THE RESEARCH

The objectives of the research were to determine normative score distributions for drivers in 10-year age groups on 3 tests under 2 levels of surround lighting. The tests were the Allen night vision performance test (NVPT) with a 10 percent contrast target, the Titmus standard acuity test (TSAT), and a Titmus low-contrast test (TLCT), a special test slide using broken-circle test objects forming a graded scale of contrast.

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The two conditions of lighting were a 10 ft-L level representing ordinary room lighting conditions and a room lighting level of about 0.2 ft-L simulating night-driving conditions. For the TSAT and the TLCT, photopic and mesopic backgrounds were 34 and 0.4 ft-L respectively.

PREVIOUS STUDIES BY OTHER INVESTIGATORS

Pease and Allen (3) and Richards (5) noted a loss in visual efficiency of older age groups at low illumination levels similar to those of night driving indicated by Richards to be about 0.2 to 0.4 ft-L. Allen and Lyle (2) reported results on a small number of subjects in tests that used targets with contrast as low as 10 percent and filters to simulate visual characteristics of older people. Those results indicated that older subjects would have special difficulty in seeing low-contrast targets.

EARLIER STUDY AT MICHIGAN STATE UNIVERSITY

Forbes et al. (6) reported a study in which the NVPT and TSAT were used. The target letters supplied were intended to present 20 percent contrast, but our measurements with a Pritchard photometer showed that the letter contrast was actually in the 50 to 60 percent range.

The results of that study showed that some subjects in the age 60 and over group and some in younger age groups had difficulty in discriminating the NVPT targets. These subjects also tended toward poor acuity scores in the TSAT at photopic and even more at mesopic illumination levels.

When NVPT scores were correlated with TSAT scores at full brightness (about 34 ft-L) representing photopic vision, correlations of 0.50 to 0.65 or higher were obtained.

PRESENT STUDY

It seemed that measurements with a lower contrast target were needed because they might show the much greater deficiency reported for older individuals by Allen and Lyle (2).

Therefore, a 10 percent contrast target (this target was supplied through the courtesy and interest of Merrill Allen) was used in a second series of measurements on another group of subjects as reported in this paper. Also, because of interest in the low-contrast vision problem, a special target for the TSAT was supplied for this research. (R. A. Sherman and the Titmus Optical Company made this special target available for use in this research.)

TEST EQUIPMENT

Two testing devices were used: the Allen night vision performance tester and the Titmus vision tester.

The Allen tester uses 20/40 dark letters presented against a luminous background. The background illumination is raised gradually until the subject is able to read 4 out of 5 test letters. The device consists of 11- by 12-in. white translucent opal glass transilluminated by four 40-W incandescent bulbs. Three rows of reversible letters on photographic film are mounted on the opal glass screen. Two neutral density filters mounted 90 deg to each other form a V in front of the stimulus field; the vertex is toward the subjects to reduce effects of room illumination. The field and filters are enclosed in a black box. An intensity control and light-intensity measurement meter are mounted in a remote-control box. A black card was hinged to cover the front of the device so that the experimenter could cover test letters while the readout meter stabilized and also during recording of the meter reading. The subject viewed the test at a distance of 10 ft.

The Titmus tester is a binocular optical device for screening visual performance. It uses, for acuity measurements, slides bearing targets composed of Landholt rings of about 90 percent contrast and varying acuity steps from 20/13 to 20/100 and 20/200. Targets are transilluminated from the rear by tungsten bulbs. The targets are enclosed in a housing, which prevents outside light from entering. This instrument may be used for measuring acuity of both eyes simultaneously, for the right eye or the left eye separately, and for other visual measurements.

In this study, the standard visual acuity tests and specially prepared graded contrast targets were used, both binocularly.

The standard acuity targets were presented at about 34 ft-L (photopic) and 0.4 ft-L (mesopic) luminance levels as were the graded-contrast targets. Each graded-contrast target presents 20/40 Landholt broken circles in a graded contrast series.

As in the earlier study, the mesopic level of lighting simulating night-driving conditions was obtained by use of 2 gooseneck lamps pointed at 45 deg to the rear of the room behind the subject and placed to produce about 0.2 ft-L on a white card on the front of the test equipment.

To simulate ordinary room lighting conditions that might be met if tests were administered in connection with driver licensing (called photopic in this report), luminance on the card was adjusted to give 10.0 ft-L. That level of room lighting was obtained with 2 banks of fluorescent-tube ceiling lights in diffusing fixtures slightly behind the subject. Similar lights in front of the subject were turned off to avoid possible glare from those sources.

Figure 1 shows a diagram of the layout of the test location in East Lansing. The testing room setup in the State Office Building in Lansing was very similar. All of the lighting conditions were checked photometrically and adjusted to be as nearly the same as possible.

SUBJECTS

A total of 397 subjects ranging in age from 16 to 70 were each given 3 different tests, each under mesopic and under photopic conditions. The number of subjects in each age group is given in Table 1. Because of incomplete records, the total number of subjects dwindled to 371 as shown below:

Age	Number
15-19	28
20-29	119
30-39	60
40-49	83
50-59	49
60+	32
Total	371

The first group of 309 subjects was obtained from new driver license applicants, from parents escorting them, and from renewal license applicants at the East Lansing office of the state driver licensing authority. Additional subjects were obtained through the courtesy of several state offices in Lansing. The latter group included a larger number of subjects in the older age groups.

PROCEDURE

The procedure was similar to that of the preceding study (6). All subjects wore glasses if they reported using them while driving at night. Each subject entered the experimental room and took a seat facing away from the lights in the back of the room and facing the NVPT instrument. The subject was "dark adapted" for approximately 5 min while the experimenter explained that the purpose of the project was to find out what most people can see under simulated night-driving conditions as compared to higher illumination conditions. The subject was told that the scores would be confidential and would not affect his or her driving record. Vision test records were identified only by number.

The Allen night vision performance test was given first, then the Titmus low-contrast test set for low illumination, and then the Titmus standard acuity (high-contrast) test, also under low illumination. Following this, the lights were turned up to the photopic room condition, and the tests were given again in the same sequence.

The graded series of contrast values for the TLCT are shown in Figure 2. The contrast values for the target letters of the NVPT and the broken-circle test objects of the TLC test were checked by measurements with a Pritchard photometer.

ANALYSIS OF THE DATA

The data were plotted as distributions by 10-year age groups. The scores of the different tests were coded and keypunched. Means, standard deviations, and product moment correlation coefficients were calculated by electronic computer. The entire group and the downtown and the East Lansing groups of subjects were analyzed together and separetely. Finally, the scores on each test were ordered, the poorest 20 percent were located, and sequential sorts were carried out to determine the number of those subjects common to each pair of tests.

RESULTS

Figures 3 to 8 show for each age group the percentage scoring at the levels indicated. Mean values are indicated by an X, and brackets to each side indicate the standard deviation of each distribution.

Figures 3 and 4 show the TSAT photopic and mesopic scores. As expected, the average scores increased with age. Mean photopic scores ranged from about 0.8 to 1.3 min of visual angle, and mesopic average acuities ranged from about 1.1 to 2.0 min of arc. The group means (Fig. 12) were similar to those of the group of subjects tested in the earlier study (6). Some subjects in each age group exhibited visual acuity scores considerably poorer than average for their age group. There were more of those in the mesopic than in the photopic acuity scores.

NVPT scores are shown in Figure 5 for photopic room lighting and in Figure 6 for mesopic or simulated night-driving room illumination. Mean NVPT scores for young to older age groups represented background luminances of about 4.0 to 40 ft-L for the photopic and about 7.0 to 55 ft-L for the mesopic scores. Each age group showed some extreme cases of poor visual discrimination. The deviant scores were much higher (indicating poorer discrimination) in this study than in the previous study. Average NVPT scores in the previous study ranged from about 0.5 to 1.6 ft-L. They also showed in each age group some subjects with much poorer scores than the rest of the group (Fig. 13).

Figures 7 and 8 show the photopic and mesopic score distributions on the Titmus low-contrast test. The average photopic scores for age groups varied from 2 to 8 percent contrast, and mesopic average scores for different age groups varied from 4 to 18 percent contrast. Again, a few cases in each age group exhibited much poorer scores than the remainder of the age group.

Figures 9, 10, and 11 show the proportion of subjects in the poorest 20 percent of each of the test score total distributions common to each pair of tests under photopic or mesopic conditions. The results of sequential sorting of the poorest 20 percent indicate that from 50 to 75 percent of the subjects in the poorest 20 percent were the same people, but the highest commonality occurred for the NVPT under the 2 lighting conditions.

Table 2 gives correlations for each combination of test scores at photopic and mesopic luminance levels. Considerable commonality is demonstrated among the scores on the different tests, but correlation coefficients indicate that the tests did not measure exactly the same visual ability. Correlations were highest between scores of the same test at photopic and mesopic levels. The NVPT was highest with a correlation of 0.867; the TSAT was next with 0.621. The TLCT showed the lowest self correlation of 0.468. Correlations between NVPT and TLCT involving low-contrast targets ranged from 0.36 to 0.50. Correlations within the subgroups and within age groups were also run and were quite similar.

DISCUSSION OF RESEARCH

Figure 12 shows that average TSAT scores of the 371 subjects in this study were very similar to those of the 396 subjects in the earlier study (6) for both the photopic

Figure 1. Layout of test equipment and lights.

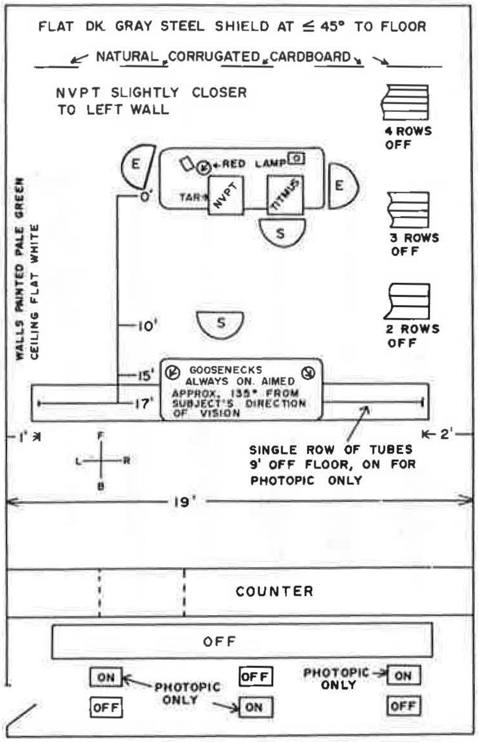


Table 1. Subjects in each age group.

Age	Males	Females	Total
16-20	18	19	37
21-25	44	38	82
26-30	26	11	37
31-35	19	12	31
36-40	25	17	42
41-45	22	25	47
46-50	27	19	46
51-55	16	10	26
56-60	18	4	22
61-65	13	3	16
66-69	6	0	6
70+	3	2	5
Total	237	160	397

Figure 2. Values used for TLCT target.

	1	2	3	4	5
A	.69	.61	.54	.48	.43
B	.38	.34	.31	.28	.25
C	.23	.20	.18	.15	.12
D	.09	.06	.04	.01	.01

BRIGHTNESS CONTRAST SCORE $\frac{(1-B_T)}{B_B}$ FROM SMOOTHED CURVE.

Figure 3. Titmus standard acuity test, photopic condition.

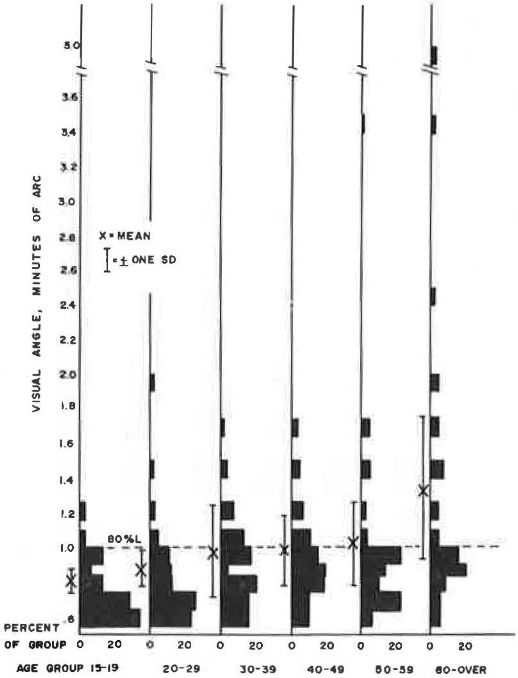
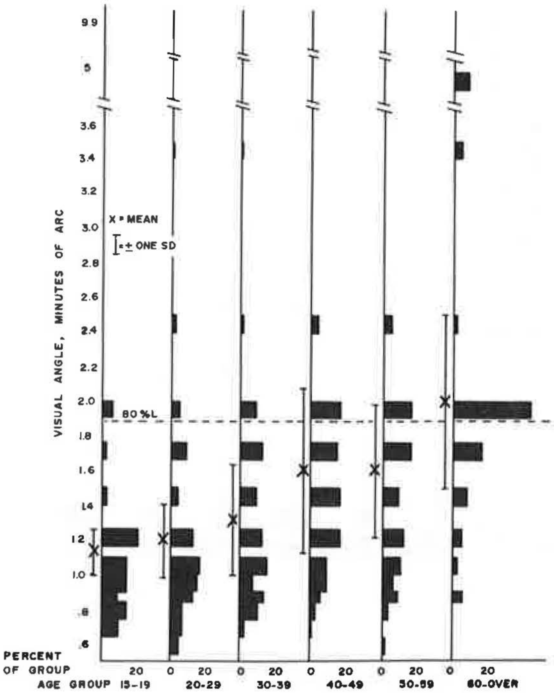


Figure 4. Titmus standard acuity test, mesopic condition.



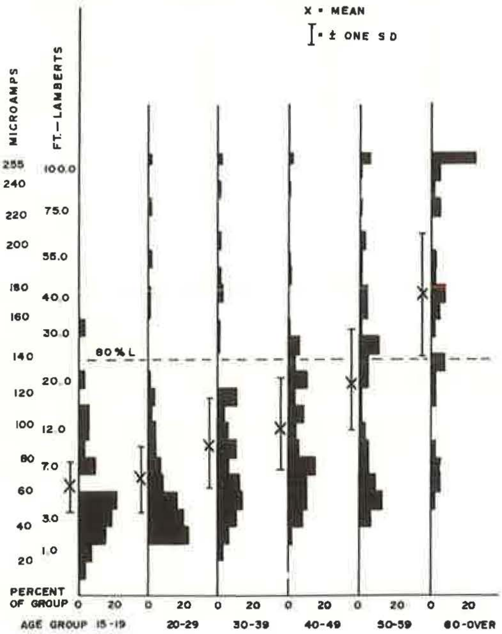


Figure 5. Allen night vision performance test, photopic condition.

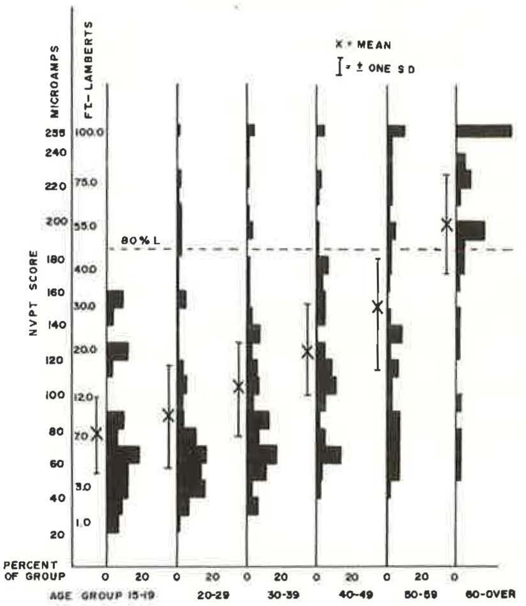


Figure 6. Allen night vision performance test, mesopic conditions.

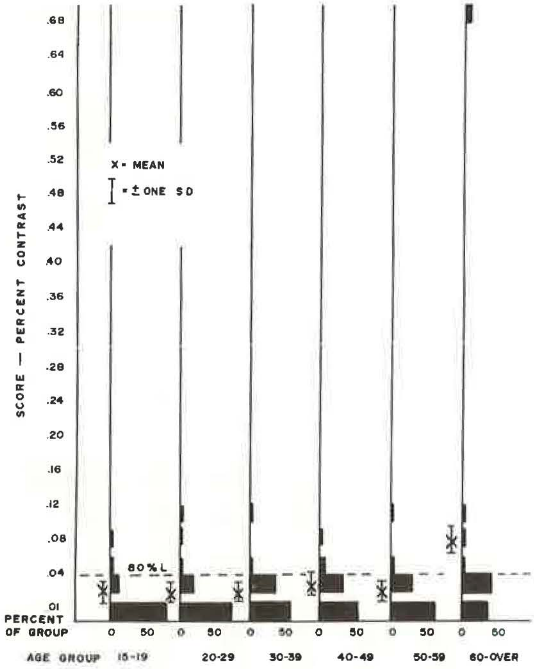


Figure 7. Titmus low-contrast test, photopic condition.

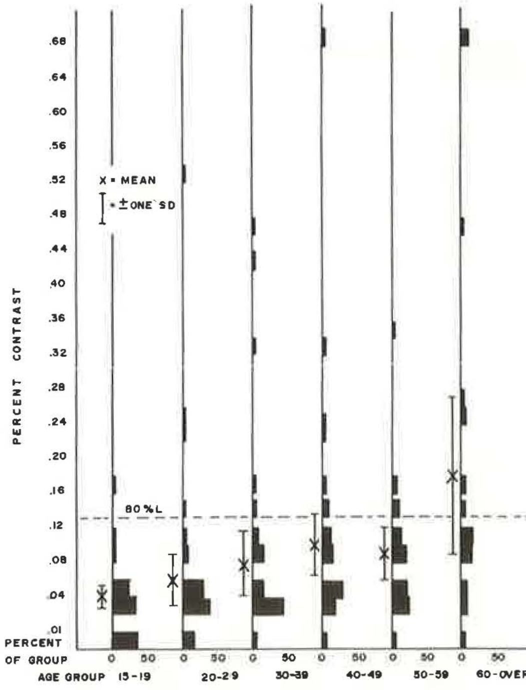


Figure 8. Titmus low-contrast test, mesopic condition.

and the mesopic levels of background luminance. The mesopic acuity correlated with the photopic about 0.62, and average acuity decreased consistently with age from about 1.0 to 2.0 min of arc. Those relations are in general agreement with results reported by Uhlaner and Drucker (7) and by Richards (5). Blackwell and Blackwell (4) report a threshold "contrast multiplier" for the 60 to 70 age group compared to the 20 to 30 age group of 2.5, which is roughly in the same range.

Table 3 and Figure 13 show that the NVPT 10 percent contrast target resulted in higher average scores (poorer discrimination) for all age groups in both photopic and mesopic conditions. Contrary to the earlier results, photopic scores (room lights on) were lower (better). Therefore, the room lighting in which the test is given is importhat when the 10 percent contrast target is used.

The poorest 20 percent of the subjects required more than 50 ft-L under mesopic and more than 25 ft-L under photopic room conditions. (The foot-lambert values shown in Figure 13 represent an average of mesopic and photopic readings taken with a Pritchard photometer.) Those levels were very much higher than the 1.0 to 1.6 ft-L in the previous study using a target contrast of 50 to 60 percent. That difference in score level again shows the effect of the 10 percent contrast target.

The 10 percent contrast target apparently introduced different factors into the visual performance. In fact, when viewing this target, a few of the subjects were unable to discriminate the test letters even with the highest luminance level available.

In the TLCT at photopic background luminance, most subjects discriminated 4 percent contrast targets, and all subjects discriminated targets at or below 12 percent contrast. At mesopic background luminance, the majority discriminated targets at 12 percent contrast or lower, but a few subjects in each age group required 20 percent or higher.

Although a majority of the subjects discriminated mesopic Titmus target contrast as low or lower than the NVPT target, very few discriminated the 10 percent NVPT target even at a 2 ft-L background luminance. Most required a much higher level. This suggests that the NVPT with the 10 percent contrast target measured some other factor than low-contrast discrimination alone.

Because the NVPT background luminances for discrimination were much higher than those in the previous study, it seems that the NVPT background may have been bright enough to introduce pupillary contraction and veiling glare to produce the poorer scores. Thus, the NVPT with the low-contrast target apparently served as a test of vision against glare. That interpretation is supported by comments of some subjects that the NVP test gave them trouble because of glare.

As in the previous study, the average scores for the different age groups showed a gradual decrease of acuity from the lowest to the highest 10-year age group. Some subjects in each of the age groups showed much poorer visual performance than the majority in their age group, and many in the older groups did as well as many in the younger groups.

CONCLUSIONS

1. Normative scores for 3 visual tests at both photopic and mesopic luminance levels were determined for 371 subjects divided into 10-year age groups. As expected, average visual performance decreased with age, but age-group scores overlapped greatly on the 3 tests.
2. The NVPT with 10 percent contrast target appears to measure ability to discriminate low-contrast targets against glare. A few subjects in younger as well as older age groups (except those under 20 years) showed poor performance compared to the majority of the people in that age group. Therefore, low-contrast vision in low illumination may be a problem for some drivers of all ages.
3. The TSAT (with about 90 percent target contrast) at low luminance level (0.4 ft-L) simulating night-driving vision conditions showed somewhat similar relations (i.e., gradually decreasing acuity from lowest to highest 10-year age groups). Some individuals with very poor scores were in younger as well as older age groups.

Figure 9. Poorest score subjects common to NVPT and TSAT.

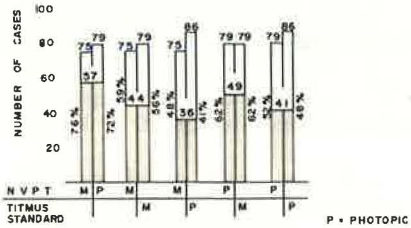


Figure 11. Poorest score subjects common to TLCT and TSAT.

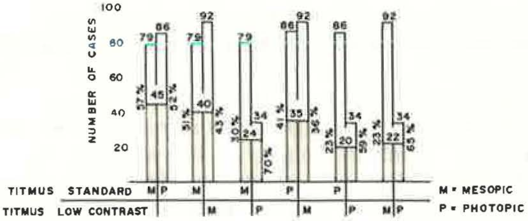


Figure 10. Poorest score subjects common to NVPT and TLCT.

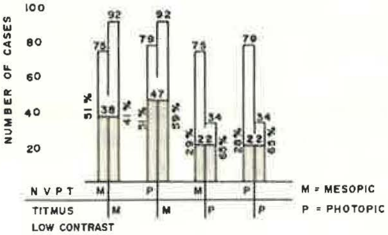


Table 2. Intercorrelation of test scores.

	Mesopic			Photopic		
Test	NVPT	TSAT	TLCT	NVPT	TSAT	TLCT
Mesopic						
NVPT						
TSAT	0.547					
TLCT	0.501	0.439				
Photopic						
NVPT	0.867	0.601	0.540			
TSAT	0.482	0.621	0.485	0.516		
TLCT	0.361	0.413	0.468	0.391	0.497	

Figure 12. Visual acuity of subjects.

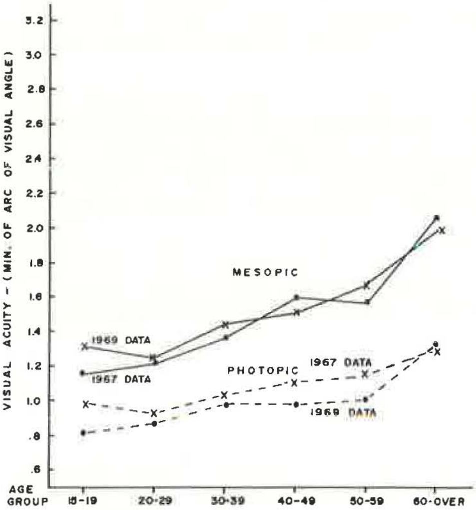


Figure 13. Effect of target contrast.

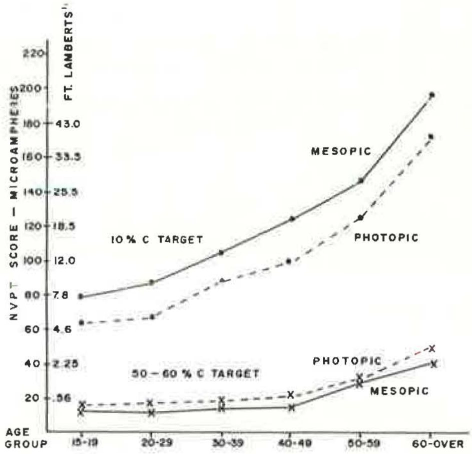


Table 3. Score averages and standard deviations by age groups.

	Mesopic						Photopic					
	Avg NVPT		TSAT		TLCT		Avg NVPT		TSAT		TLCT	
Age Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
15-19	78.93	37.28	1.16	0.32	0.05	0.04	63.68	31.84	0.81	0.16	0.02	0.02
20-29	87.13	53.05	1.21	0.51	0.06	0.06	67.65	42.82	0.87	0.26	0.02	0.02
30-39	104.63	59.36	1.36	0.70	0.08	0.08	87.27	54.53	0.98	0.57	0.03	0.02
40-49	123.67	58.12	1.60	1.05	0.11	0.10	98.63	49.70	0.98	0.27	0.03	0.02
50-59	146.29	68.08	0.57	0.73	0.09	0.06	124.53	60.71	1.01	0.45	0.02	0.02
60+	196.97	61.40	2.06	0.95	0.18	0.19	173.22	73.50	1.34	0.90	0.08	0.17
All	115.47	65.54	1.44	0.79	0.09	0.09	94.38	60.04	0.97	0.44	0.03	0.05

4. In the TLCT, however, many subjects discriminated targets at 12 percent contrast or lower, but some in each age group required 25 percent contrast or higher for discriminating the broken-circle test objects.

5. Correlations of the different test scores ranged from 0.36 to 0.55 for the tests involving low-contrast targets. Photopic and mesopic scores for each test showed higher correlations (0.55 to 0.87).

6. Each of the tests must be interpreted in terms of its own normative score distribution by age groups.

7. A difference has been demonstrated in the ability to discriminate low-contrast targets against a background of low-level luminance as compared to the ability to discriminate a very low-contrast target against a background of increasing luminance that may reach levels of glare. The NVPT appears to measure ability to see low-contrast targets against glare, whereas the TLCT apparently measured ability to discriminate low-contrast targets as such.

8. Although, as expected, subjects in the 50 to 60 age group showed poorer scores on the average, many did as well as most younger subjects. Some younger subjects had much poorer vision than their own age group and than most of the older subjects. Therefore, individuals should be made aware of such deficiencies regardless of age.

9. Use of the tests for selection or licensing is not recommended because no actual relation has been demonstrated to safe driving. However, use of such tests for informing drivers and alerting them to the existence of visual problems is probably desirable because of the possible relation to safe driving.

10. If the tests are used for informing and educating drivers and for research purposes, norms must be determined for the particular test and target contrast used as well as for the surrounding room illumination in the case of the NVPT with a very low-contrast target.

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We are pleased to acknowledge the assistance of David Bieler, Joseph Schuler, and Jack Ferrara in making the measurements in 1968-69 and of Jack Ferrara, Gerry Burtnett, and Douglas Williams with analysis of the results later. We should like to express thanks for the cooperation and assistance of staff and others in the Office of the Secretary of the State of Michigan, the Michigan Department of Highways, and to those who voluntarily served as subjects.

REFERENCES

1. Allen, M. J. Night Vision Performance Tester, Laboratory Model. Div. of Optom., Indiana Univ., 1966, p. 3.
2. Allen, M. J., and Lyle, W. M. The Relationship Between Night Driving Ability and the Amount of Light Needed for a Specific Performance on a Low Contrast Target. Jour. Amer. Optom. Assn., Vol. 34, 1963, pp. 1301-1303.
3. Pease, P. L., and Allen, M. J. Low Contrast Visual Acuity and the Effects of Ambient Illumination, Filters and Scatter. Amer. Jour. Optom., April 1967.
4. Blackwell, O. M., and Blackwell, H. R. Visual Performance Data for 156 Normal Observers of Various Ages. Jour. Illum. Eng. Soc., 1971, pp. 3-13.
5. Richards, O. W. Vision at Levels of Night Road Illumination and Changes of Acuity and Contrast Sensitivity With Age. Amer. Jour. Optom., Vol. 43, 1966, pp. 313-319.
6. Forbes, T. W., Pain, R. F., Bloomquist, D. W., and Vanosdall, F. E. Low Contrast and Standard Visual Acuity Under Mesopic and Photopic Illumination. Jour. Safety Res., Vol. 1, 1969, pp. 5-12.
7. Uhlaner, J. E., and Drucker, A. J. The Army Night Screening Tester—Development and Use. National Technical Information Service, Springfield, Va., AD 258 349, 1961.

TOWARD THE DEVELOPMENT OF A METHODOLOGY FOR EVALUATING HIGHWAY SIGNS BASED ON DRIVER INFORMATION ACQUISITION

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This paper presents the findings of a research study conducted to develop a methodology for evaluating road signs by the use of an eye-marker camera as a primary research tool. The methodology attempts to evaluate a road sign by determining the degree of match between the sign-reading behavior of drivers and the characteristics of the signs, the highway, and the traffic situations. Data were collected on the eye movements of drivers under actual driving situations involving more than 400 different Interstate highway signs. The data were analyzed by specially developed computer programs that also computed sign evaluation measures describing sign-reading behavior of the drivers. Further analyses showed that the sign evaluation measures were related to many factors associated with the characteristics of the signing, the driver, the highways, and the traffic situations. Understanding how various factors influence sign-reading behavior provides a basis for the implementation of the methodology for both the evaluation and the design of highway signing.

•THE PROBLEM of evaluating signs by determining the degree of "match" among the characteristics of the signs, the abilities of the drivers, and the other components of the highway such as the traffic and road geometrics was the focus of this research. The evaluation of the road signs was accomplished by using an eye-marker camera.

The eye-marker camera system provides continuous records of the driver's eye movements (i.e., where the driver's eyes are directed while driving) superimposed on the driver's view of the forward road scene, which includes important information such as traffic flows, sign configuration, and layout as the vehicle proceeds down the highway. The analyses of the eye-movement data recorded on film (or video tapes) enables a researcher to determine how a driver acquires, or does not acquire, information from oncoming road signs.

The use of an eye-marker camera system as a primary research tool for the evaluation of highway signs results in benefits not realizable with other types of measuremen systems. One of those benefits is lack of bias. Eye movements are, to a large extent, involuntary and thus relatively bias free when compared with other types of driving performance parameters. Another benefit is lack of prejudice due to instructions. The reliance on information acquisition and control performance measures enables data concerning signing to be obtained without instructional references to the signing interest. For example, the instructions "Drive in your normal manner and exit at US-62' require that the driver rely on route guidance and regulatory signing without being specifically told about any of the signs that are being studied.

Further, an extensive review of signing-research literature conducted in the early stages of this research suggested that most signing research was conducted in the following 3 areas:

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1. Sign legibility (i.e., determination of effects of factors such as contrast of letters, height of letters, and stroke width on legibility distances),
2. Sign visibility (i.e., determination of effects of factors such as area of sign, color, and brightness contrast with background on "target value" or "attention value" of a sign), and
3. Driver's reactions to highway signing (which includes studies conducted by collecting data through traffic observations, e.g., erratic driver maneuvers, or driver interviews).

The literature in the areas mentioned above does not clearly address the basic question, How do drivers acquire or fail to acquire information from a sign? Clearly, because the information displayed by the sign is acquired visually by the drivers, the collection of eye-movement data to investigate sign-reading behavior of drivers is important. Both the consideration of the driver's visual capabilities (e.g., visual acuity) and the consideration of the driver's sign-information-processing capabilities and sign-reading behavior play a crucial role in the proper evaluation of highway signing.

OVERVIEW OF RESEARCH

The primary aim of the signing research involving eye-movement recordings was to develop an assessment technique for the evaluation of highway signs. The objectives of the research were, therefore, as follows:

1. To develop a scheme for measuring sign-reading behavior of drivers based on their eye movements;
2. To identify important variables related to the characteristics of the various components, such as drivers, signs, highways, and traffic, that affect the sign-reading behavior of the drivers;
3. To investigate the effect of those important variables on the sign-reading behavior of drivers;
4. To develop a methodology for evaluating road signs on the basis of the observed relations between sign-reading behavior and characteristics of signs, highways, and traffic; and
5. To use the developed methodology to evaluate various signing situations.

The experimental work in this 3-year research study included a set of 8 field studies and 3 laboratory experiments. In the field studies, the eye movements of test drivers were recorded under actual driving conditions for more than 400 Interstate highway signs. The 3 laboratory studies were conducted to relate sign reading under controlled laboratory conditions to the same signs studied under actual road conditions.

The objectives and experimental procedures of the studies are presented briefly in a later section of this paper. The objectives of each of the 11 studies were such that they collectively provided information for determining effects of the following variables on the sign-reading behavior of drivers:

1. Factors related to differences in signing characteristics, including (a) letter size, (b) length of message, (c) relevancy of message with respect to exiting or route-following instructions, (d) type of mounting, (e) number of signs in a sequence of signs presenting the same route-guidance information, and (f) multiple signs or number of signs at a location;
2. Factors related to drivers, including (a) binocular visual acuity of the driver's visual field, (b) characteristics of driver's informational needs (i.e., type of information needed and urgency of the informational need), and (c) driver's familiarity with the highway;
3. Factors associated with visual load on the drivers, including (a) traffic density (car-following demands) and (b) special driving instructions (e.g., in one of the studies, the driver's instructions were, "Stare at the lead car as much as possible and exit at Cleveland Avenue");
4. Factors related to highway geometry (i.e., the relation of the characteristics of signing to the characteristics of the geometric design of the highway), including

(a) signing at the most commonly designed highway geometric situations (e.g., standard right exit) and (b) situations where signs present information contradictory to the geometric highway design (e.g., signing requiring a turn to the south in order to eventually go north).

MEASUREMENT OF SIGN-READING BEHAVIOR FROM EYE MOVEMENTS

The sign-reading behavior of the driver can be defined as the visual behavior that is responsible for acquiring the information displayed by the sign. The driver's eye movements while he approaches a sign are only one of the variables that are needed in understanding how a driver acquires the information from the sign. More specifically, to evaluate whether a driver can or actually does acquire the information involves consideration of the following factors:

1. Characteristics of the sign (e.g., sizes of letters, contrast of letters with sign background, and size of sign),
2. Characteristics of the driver (e.g., his visual capabilities, eye movements, attention, and information processing loads),
3. Characteristics of visual information transmitting medium (e.g., visibility under different weather conditions),
4. Driver's location and path of motion on the highway with respect to the sign, and
5. Vehicle speed.

Further, while he is driving, the driver's eyes do not continually sample information but make successive discrete "fixations." A fixation can be defined as an apparent stationary position of the eyes between 2 successive eye movements. A driver can extract information from the optical image on his retinas only in a fixation (6). The durations of fixations while one is driving generally range between 100 to 600 msec.

The problem of measuring sign-reading behavior is, therefore, the same as the problem of measuring fixations during which the driver acquires information from an oncoming sign. Further, the problem of determining the fixations in which a driver can and cannot obtain information from a sign is extremely complex. One of the primary reasons for that complexity was found during the course of this research. The driver need not make direct fixation on a sign (i.e., directly point his eyes or visual axis on the sign) but can obtain information from the sign from extra-foveal parts of his visual field provided the visual capability of the portion of the visual field (where the image of the sign, i.e., the displayed message, forms) is high enough to be resolved (1).

Therefore, the visual information displayed by a sign can be considered to be available to a driver only if the optical image of the sign formed on his retinas while he is driving is "resolvable." The image of the sign can be considered to be resolvable only if the letters (or numbers or symbols) displayed on the sign form an image that is clear enough such that a driver with a given acuity can extract information when needed. To determine resolvability of letters on a sign in the driver's visual field, we made the following assumption: A letter (or number) on a sign is considered to form a resolvable image on a driver's retina if the angle (measured in minutes) subtended by the height of the letter (or number) is greater than or equal to 5.5 times the resolution angle (i.e., reciprocal of visual acuity) at that radial position (i.e., eccentricity) on the retina where the image of the letter is formed.

A detailed discussion of the considerations involved in making the above assumption and the definition of visual acuity are given by Rockwell et al. (5), LeGrand (4), and Davson (3). The above assumption was supported by conducting controlled field studies in this research (1). All field studies were conducted under daytime luminance levels ranging between 10 to 10^4 cd/m^2.

A computer program was developed to determine the availability (or resolvability) of information displayed by a sign to a driver in the successive eye fixations he makes as he approaches a sign. The program, which is called SEADEM (sign evaluation by analysis of driver eye movements), requires the following inputs:

1. Eye-movement data collected on the test section (eye-movement data consist of angular coordinates and durations of successive eye fixations made by the test driver as he approaches a sign);
2. Highway geometry;
3. Velocity profile and the path (i.e., lane position) of the test vehicle on the test section;
4. Sign characteristics, such as location of sign, sizes of letters, sign size, and contrast; and
5. Visual acuity in the binocular visual field of the test driver.

With those inputs, SEADEM determines the eye fixations that provide resolvable information about the sign to the driver and then computes the following measures that are used to define the sign-reading behavior of the driver (Fig. 1):

T_{max} = maximum time-distance during which information displayed by the largest letter or symbol on the sign can form a resolvable image on the driver's retina if the driver were fixating foveally on the sign;

T_f = time-distance at the beginning of the first fixation when the largest letter (or number) on the sign forms a resolvable image on the driver's retina;

T_e = time-distance at the last fixation when a letter (or number) on the sign forms a resolvable image on the driver's retina;

T_t = $(T_f - T_e)$ = time interval in which perceptual time is shared with the sign and the tasks in driving;

T_{used} = total time during which information displayed by the sign forms a resolvable image on the driver's retina (this represents total time available for obtaining information from a sign); and

T_{emin} = minimum possible value of T_e below which a sign cannot present resolvable information to a driver because of limitation of driver's visual capabilities, angular position of the sign, and angular velocity of the sign in the driver's visual field.

In addition to the above measures, another measure called T_{min} was defined as the minimum time necessary for an unfamiliar driver to acquire information displayed by a sign.

For purposes of determining values and distributions of T_{min} as a function of variables such as length of displayed message and type of informational need of the driver in relation to the message displayed by the sign, a controlled experiment using a research sign that can be programmed was conducted. The description of the experiment is given in another report (1). The measure T_{min} was defined primarily to enable comparison between the observed values of T_{used} and T_{min} for the same sign and to investigate the problems related to partial or excessive sign reading by the drivers.

HYPOTHESIZED RELATIONS

The variables defined above were conceptualized (either by definition or for experimental testing) to be functionally related to various factors such as sign characteristics, driver familiarity with the route, and traffic density. A partial list of functional relations is briefly presented as follows:

T_{max} = f (size of letters, speed of vehicle, visual acuity, and location of driver with respect to sign);

T_{used} = g (traffic characteristics, familiarity, complexity of message on the sign, and highway geometry);

T_f = h (sign detection, urgency of information, traffic characteristics, visual acuity, and height of largest letter);

T_e = k (complexity of message, familiarity, T_f, height of the largest letter, and relevancy of message);

T_{emin} = l (relative angular position of sign with respect to driver's path, velocity, and visual acuity); and

T_{min} = m (complexity of message, familiarity, and relevancy of message).

In this research, the relevancy of the message displayed on the sign to the driver was defined by considering the following 3 categories:

1. Signs that are not relevant (NR), i.e., the driver does not need information to continue on the highway;
2. Signs that are not pertaining (NP) to route, i.e., that do not present information pertaining to route or destination; and
3. Signs that are pertaining to route (PR), i.e., that present relevant information pertaining to route or destination.

The following important basic hypotheses are some that were developed to investigate the functional relations presented above:

1. The time-distance at the first fixation from which the driver begins to sample information from a sign would be related to T_{max}. More specifically, it is hypothesized that, the higher the value of T_{max} is, the higher the value of T_f will be.
2. The measure T_f depends on the driver's informational need and on the visual load on the driver's information acquisition and processing capacity due to other driving tasks. It was hypothesized that, with an increase in the urgency of the information to the driver, the value of T_{max}/T_f would tend to move close to 1.0. Further, it is hypothesized that, with an increase in visual load (primarily due to traffic density), the value of T_{max}/T_f would increase.
3. The total time, T_{used}, during which a driver obtains information from a sign depends on (a) $(T_f - T_{emin})$ = total time available to the driver to obtain information from the sign, (b) relevancy of information presented by the sign in relation to driver's information need, (c) amount of message presented on the sign, and (d) visual information demands in performing other tasks in driving. The difference $(T_f - T_{emin})$ defines the maximum time that is actually available for a driver. It is, therefore, hypothesized that, depending on the information need, the driver time-shares his visual attention (in the period $T_f - T_{emin}$) between the sign and other sources that provide him information necessary to perform other driving tasks. The time-sharing process is further hypothesized to be a trade-off type of process where the driver has to make decisions on (a) proportion of $(T_f - T_{emin})$ time to be spent between acquiring information to perform other tasks in driving, (b) percentage of needed information to be acquired from a sign without interpretation errors, and (c) urgency associated with obtaining the information from a sign.
4. The ratio T_i/T_{used} is hypothesized to be a descriptor of the trade-off process mentioned above. The signs for which values of T_{used} are higher and the values of T_i/T_{used} are lower would then indicate the driver's increased concentration on the signs. Therefore, it is hypothesized that the important criteria for determining "adequacy" of a sign are (a) T_{max}/T_f should be as small as possible [the time period $(T_{max} - T_f)$ indicates unused time, i.e., a driver does not use the available information from the sign], and (b) values of the ratio $[(T_f - T_{emin})/T_{min}]$ should be greater than or equal to T_i/T_{used} (T_{min} is defined as the time required by an unfamiliar driver to obtain the needed information with no interpretation errors and, if less than T_{used}, indicates that the driver did not obtain all the information adequately or only partially read the sign).

SOME DETAILS CONCERNING THE FIELD DATA COLLECTION

The hypotheses presented in the previous section were investigated and the effects of many other factors on the sign-reading behavior of drivers were determined in 8 field studies. Table 1 gives some details concerning the studies. Details concerning each of the studies are given in the final report of this project (1).

In all 8 studies, the data were collected by using an instrumented vehicle that was equipped to record simultaneous synchronized data on eye movements and driving performance. The eye-marker camera system used in this research works on the principle of corneal reflection. The system essentially records superimposed images of the position of the driver's visual axis and the driver's forward visual scene encompassing a 20 x 20-deg visual field. A detailed description of the eye-marker camera system, the instrumented vehicle, and the data collection procedure used in this research is given in another report (1).

Most of the eye-movement data in this research were collected under experimental conditions, and the subject drivers were totally unaware of the objective of the research. In the field studies, drivers were only given freeway entering and exiting instructions, and nothing was mentioned to them about the signing. The collection of eye-movement data, thus, enables the researcher to obtain unbiased (instruction-free) data on the sign-reading behavior of drivers during a period of time. Field studies F-2 and F-5 (Table 1) included testing under controlled situations where specially designed research signs were erected and employed with the cooperation of the Ohio Department of Highways. In all the field studies, the total eye-movement data collected in this study amounted to more than 2,000 sign passages. The data were analyzed by the SEADEM computer program, and sign evaluation measures were computed.

The 3 laboratory studies in this research were conducted primarily to investigate the effect of message content and informational need of the driver on the minimum time necessary to acquire information from a sign. The laboratory studies are described in the earlier report (1).

RESULTS

Many results were obtained from the 11 studies. In this section, basic findings are presented first and then some specific results are illustrated. Further, it is important for the reader to know the range of values of the different measures that were obtained in the studies.

Five subjects were used in this research. Their binocular foveal visual acuities ranged between 20/15 and 20/35. In general, the 50th percentile values of the measures T_{max}, T_f, and T_n for standard freeway signs and travel speeds of about 60 mph ranged from 11 to 16, 7 to 10, and 1 to 4 sec respectively. The values of T_{used}, in general, ranged between 0.5 and 4 sec.

The sign-reading behavior of a driver is a highly adaptive process. While the driver adapts his sign-reading behavior depending on relative level and importance of factors such as traffic density, relevancy of the sign with respect to the driver's intended destination, and driver's familiarity with the highways, there are some basic and relatively stable relations between T_{max}, T_f, and T_{used}. The word "stable" is used here to indicate that the relations do not appear to be appreciably affected by factors such as those described above. The basic and stable relations found among T_{max}, T_f, and T_{used} are as follows (Table 2):

1. T_{max} and T_f were found to be significantly and positively correlated under all types of driving and signing conditions;
2. T_f and T_{used}, in general, were found to be significantly and positively correlated under all types of driving and signing conditions; and
3. T_{max} and T_{used}, in general, were found to be uncorrelated.

The variable T_f (defined as the first time-distance from which a driver actually begins to sample information from a sign) is the key variable for both the evaluation and the design of road signs. That is primarily because how a driver acquires information from the sign depends highly on when he begins to attend to the sign. The period (T_f - T_{emin}) denotes the time that is available to the driver to read the sign before he passes it. Therefore, the results indicate that, depending on his informational need, the driver adapts his sign-reading behavior in the period (T_f - T_{emin}) to obtain required amounts of information during time T_{used} from the sign. Some positive correlation between T_{max} and T_f is expected because of the manner in which they are derived. T_f is dependent on eye movements, but T_{max} is independent of eye movements. The primary factors that are needed for the determination of T_{max} are maximum letter size (i.e., the highest size letter on the sign), visual acuity of the driver, velocity of the vehicle, and location of the sign with respect to the driving lane. It appears, therefore, that the positive correlation of T_{max} and T_f suggests that, as a driver approaches a sign, the

Table 1. Summary of field studies.

Number	Title	Objectives	Dependent Variables	Independent Variables
F-1	A study for developing data based on sign-reading behavior of drivers	To collect driver eye-movement data under different signing and traffic conditions to generate a data base, primarily intended for use in developing an understanding of sign-reading behavior of drivers and subsequently in developing a methodology for evaluating road signs	Sign evaluation measures	Relevancy of signing to the driving task (3 levels), i. e., no relevancy, relevant but not pertaining to route, and relevant and pertaining to route Type of mounting, side and overhead mounted Visual loading level, i. e., open-road driving, car following, and car following at minimum safe distance Signing density, low and high
F-2	A controlled validation study using speed-limit signs	To determine maximum sight distances from which a driver can read a sign To determine relation of sight distance to visual acuity of drivers To determine effect of lateral placement of signs on sign-reading behavior of drivers	Maximum sight distances at the initiation of driver control response Sign evaluation measures	Speed prior to response to speed-limit sign (4 levels) Height of letters on speed-limit signs (2 levels) Lateral position of sign (2 levels)
F-3	An exploratory study for investigation of sign reading by extra-foveal vision	To investigate possibility of a driver's sign reading by extra-foveal vision for the validation of assumption used in the developed methodology	Amount of message read by the driver	Location of fixation point (2 levels)
F-4	A study for the evaluation of sign changes on I-90	To apply the developed methodology for evaluating sign changes made by Ohio Department of Highways on I-90 in Cleveland	Sign evaluation measures	Signing differences, old and new signing
F-5	A study for determination of T_{reqd} using research sign that can be programmed	To determine minimum time necessary for a driver to acquire required information from a sign	T_{reqd} = minimum time (sec) required to acquire required information from sign	Length of message, lines (2 levels) and words (2 levels) Familiarity (2 levels) Type of information needed
F-6	A study for the investigation of effects of sequential and multiple signs	To investigate the effect on sign-reading behavior of drivers of number of signs per location (multiple signs) and number of locations of sign (or signs) per exit (sequence of signs)	Sign evaluation measures	Number of signs per location (3 levels) Number of sign locations per exit (3 levels)
F-7	A study of signing in Akron	To determine effects on sign-reading behavior of drivers of signs that provide information conflicting to highway geometrics	Sign evaluation measures	Geometric configurations, i. e., right turns for continuing on highways on left side, left turns for continuing on highways on right side, and left exit
F-8	A study of signs of special interest	To study sign-reading behavior of drivers under signing situations that are generally regarded as confusing, have special merging signs, and have diagrammatic signs	Sign evaluation measures	Signing situations

Table 2. Correlations of T_{max}, T_f, and T_{used}.

		T_{max} and T_f		T_f and T_{used}		T_{max} and T_{used}	
Number	Condition	Correlation	Significance Level	Correlation	Significance Level	Correlation	Significance Level
F-1	Open-road driving	0.3291	< 0.05	0.3077	< 0.25	-0.0466	
	Normal car following	0.2973	< 0.10	0.3780	< 0.10	-0.1069	
	Car following at minimum safe distance	0.2412	< 0.05	0.5334	< 0.01	-0.16025	
F-4	Old signs on I-90	0.552	< 0.01	0.186	< 0.10	0.064	
	New signs on I-90	0.642	< 0.01	0.415	< 0.05	0.197	< 0.05
F-6	Car following under instructions to stare at the lead car	0.505	< 0.05	0.684	< 0.05	0.268	
F-7	Difficult route selection in moderate to heavy traffic density	0.497 to 0.769	< 0.25	0.416 to 0.902	< 0.01	0.48 to 0.853	< 0.01

time-distance from which the driver first obtains the resolvable information from the sign depends on the driver's awareness of the legibility of the maximum-sized letters (presumably by extra-foveal vision, which is also generally responsible for the detection of the sign).

Table 3 gives the effects of some important independent variables on the sign evaluation measures. The arrows show the directions in which the sign evaluation measures were found to be related with increases in the value of each of the independent variables. For example, the first row of the table shows that, in general, as the traffic density increases, (a) T_{used}, T_f, and T_t decrease; (b) T_{max}/T_f decreases; and (c) values of T_e and T_t/T_{used} appear to be unaffected.

In the following paragraphs, some of the important and specific results are presented briefly:

1. The T_{max}/T_f ratio was found to be a good descriptor of the sign utilization by the drivers; if T_{max}/T_f is equal to 1.0, the driver can begin to acquire information from the sign as soon as it is legible. The higher the value of T_{max}/T_f is, the less is the utilization of the information availability of the sign. The T_{max}/T_f ratio increases as the visual load on the driver's information acquisition process increases. For the same drivers, the values of the T_{max}/T_f ratio were higher under car-following situations than under open-road situations (Fig. 2). The T_{max}/T_f ratio decreased as urgency in obtaining sign information increased. The values of T_{max}/T_f, in general, were higher for side-mounted signs than for overhead-mounted signs.

2. T_{used} was found to be related in various ways to different factors.

a. T_{used} is significantly and positively correlated to T_f, indicating that, if T_f is higher, a driver can spend more time in obtaining information from the sign (Table 2).

b. T_{used} increases as relevancy of the information presented by the sign in relation to the driver's objectives increases (Fig. 3).

c. T_{used} is related to the driver's visual load due to traffic situations. As the traffic density increases, the time that is available for the drivers to obtain information from the signs decreases (Fig. 3).

d. T_{used} depends on the amount and the type of information the driver needs. T_{used} increases as length of sign message increases. Further, values of T_{used} were smaller when the information required by the driver was displayed on the sign than when the displayed information did not contain the information required by the driver.

e. In a sequence of signs such as X ROAD, EXIT 1 MILE; X ROAD, EXIT ½ MILE; X ROAD, EXIT NEXT RIGHT, the values of T_{used} for the first sign are generally higher than those on subsequent signs, except for the last sign (or signs) where a major control action such as exiting or lane changing is required.

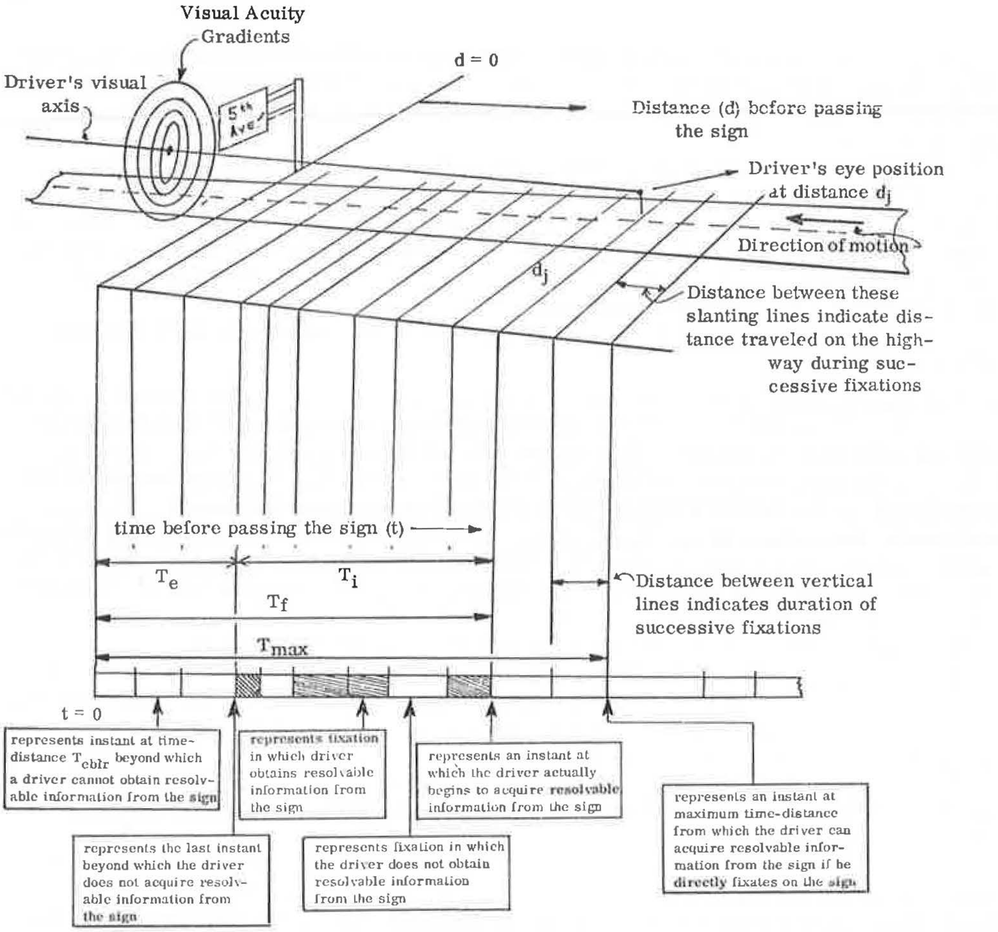
f. When a driver approaches a group of signs, the values of T_{used} are governed by the natural tendencies of the driver in relation to his objectives and positional expectancy of relevant signs and by the fact that a driver who wants to continue on the highway (i.e., in through traffic) generally spends more time looking at the signs on the left side and a driver who wants to exit generally spends more time looking at signs on the right side.

g. As the driver becomes familiar with a sign, he requires less time to obtain information from it. T_{used} is negatively correlated to driver familiarity; but if the signing is inadequate, poor, or confusing at low levels of increasing familiarity, T_{used} decreases as familiarity increases (Fig. 4). (In Figure 4, F1 represents the situation of an unfamiliar driver, and F2 represents the situation of an unfamiliar driver driving the second time on the test route.)

h. Drivers do not just concentrate on a sign (after T_f) until they obtain the required information from the sign but share their time after T_f between the sign and objects on the road. It appears that under normal freeway driving situations (i.e., under low to moderate visual loads) and for adequate signs the driver time-shares with the signs such that the 50th percentile values of T_t/T_{used} lie between 3.00 and 4.00.

i. The drivers, in general, do not read all the information displayed by a sign but make trade-off decisions between amounts of information to be acquired from the sign and time to be spent in performing other driving tasks.

Figure 1. Measures used to define sign-reading behavior of drivers from eye movements.



Note: T_{used} = sum of durations of all fixations that provide the driver resolvable information from the sign to the driver (Note: These are shown in the above illustration by ▨ .)

Figure 2. Effect of traffic density on T_{max}/T_f.

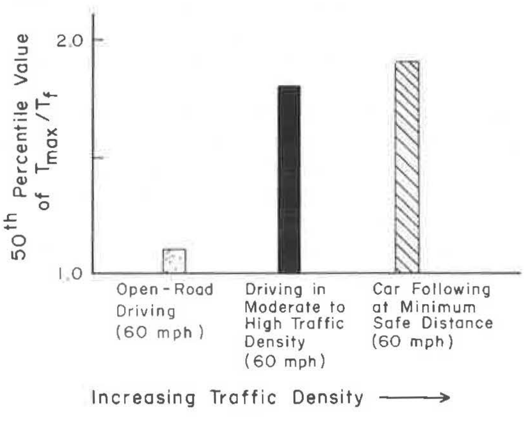
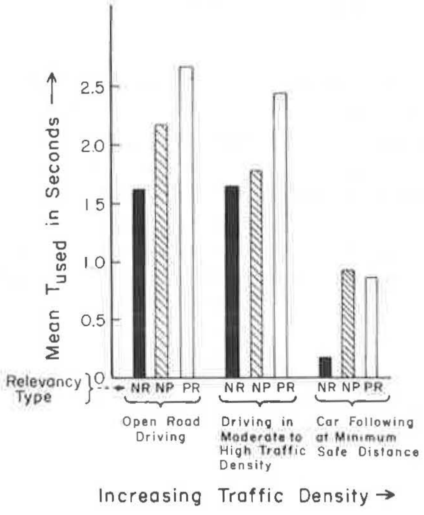


Figure 3. Effect of signing relevancy and traffic density on T_{used}.



j. As the relevancy of signing with respect to the driver's informational need increases, the values of T_l/T_{used} decrease.

3. The minimum time necessary to acquire required information from a sign is related to different variables.

a. T_{min} decreases as driver familiarity increases.

b. T_{min} increases as the amount of message read by the driver increases (Fig. 5). (In Figure 5, IN1 = searching for the mileage number for a given destination, IN2 = searching for a given destination when it was displayed along with other destinations, and IN3 = searching for a given destination when it was not displayed on the sign.)

c. When a driver is looking for specific information (e.g., a destination, the minimum time necessary to obtain such information depends on the position of that information on the sign. Drivers, in general, read the signs from top to bottom. Therefore, if the required information is displayed on the top line, T_{min} is the smallest.

d. In general, less search time is required when the information needed by the driver is presented on the sign than when the required information is not presented on the sign (Fig. 5). Further, when a driver is searching for specific information on a sign, the minimum time necessary to search and acquire the information increases as the amount of words and lines displayed on the sign increases (Fig. 5).

4. A negative for $(T_{used} - T_{min})$ indicates either that the driver read only a partial message from the displayed message on the sign or that the driver is familiar with the highway or read more completely the preceding signs.

5. When a verbal response to signing was requested from the subjects, their sign reading in the laboratory correlated to their sign reading on the road. But the road-sign reading generally requires about 300 msec additional time. Further, the sign-reading behavior of drivers under normal conditions (i.e., when the drivers were simply asked to follow a given route) is different from their behavior when they are asked to verbally report the information concerning the given route. The difference is due to a difference in a driver's strategy in reconfirming or reassuring himself about the message on the sign.

6. The sign-reading behavior of drivers on unfamiliar roads where the signing is confusing (or contradictory) and inadequate had the following characteristics: high values of T_{max}/T_f (more than 2.0); low values of T_l/T_{used} (less than 2.5); and very low values of T_e (approximately equal to T_{emin}).

PROJECTED IMPLEMENTATION OF THE RESULTS

The results obtained in this research, in general, provide information on understanding how drivers obtain information from signs under different driving and signing conditions. Therefore, as stated earlier, the problem of the evaluation of signs can be effectively solved if a proper match is achieved between the sign-reading behavior of drivers and the characteristics of the signing and related variables such as traffic density and highway geometry.

When all the results obtained in this research are assembled, they suggest that the most important variables associated with determining the degree of match between a sign and the sign-reading behavior of drivers are as follows:

1. T_f (defined as the maximum time-distance from which the driver first begins to acquire information from an approaching sign),
2. T_{emin} (defined as the minimum time-distance from which a driver can obtain information from the sign),
3. T_{min} (defined as the minimum time necessary for the driver to obtain the required information from the sign), and
4. T_{used} (defined as the time during which a driver obtains or can obtain information from a sign).

Those 4 variables, when further analyzed in relation to the following variables, provide detailed information on how a driver shares or uses the time period $(T_f - T_{emin})$: difference between T_{used} and T_{min}, T_l/T_{used}, $(T_f - T_{emin})/T_{min}$, and relations between T_f and T_{max} when considered by the ratio T_{max}/T_f. The last variable provides information about the driver urgency and use of the sign information availability.

Table 3. Effect of increase in value of independent variable on sign evaluation measures.

Number	Independent Variable	T_{used}	T_r	T_e	T_t	T_{max}/T_r	T_t/T_{used}
1	Traffic density (open-road driving to car following)	↓ F-2	↓ F-1 F-6 F-7	UA	↓ F-1 F-6 F-7	↑ F-1 F-6 F-7	UA
2	Signing relevancy to driving task	↑ F-1 F-4	NAE	↓ F-1	↑ F-1	NAE	↓ F-1 F-4
3	Type of informational need	→ F-5 L-2	NC	NC	NC	NC	NC
4	Urgency associated with obtaining information from sign	NC-NA	↑ F-4	NC-NA	NC-NA	↓ F-4	NC-NA
5	Driver's familiarity with the highway (or signs)	↓ F-4 F-5 L-1 L-2	↓ F-4	↑ F-4	↓ F-4	↑ F-4	UA
6	Average angular location of sign from path of vehicle	↓ F-4	↓ F-2 F-4	↑ F-4	↓ F-4	↑ F-4	NAE
7	Location of sign in sequence of signs	→ F-1 F-4 F-6	→ F-1 F-4 F-6	→ F-1 F-4 F-6	→ F-1 F-4 F-6	→ F-1 F-4 F-6	→ F-1 F-4 F-6
8	Position of sign in group of (multiple) signs	→ F-7	→ F-7	→ F-7	→ F-7	→ F-7	→ NAE
9	Awareness of sign and its legibility (size of sign and size of letters)	NC	↑ F-4	NC	NC	↓ F-4	↑ F-4
10	Amount of message (i. e., words, lines, and letters) on sign and message complexity	↑ F-4 F-5 L-1 L-2 L-3	NA-NC	↓	↑	NA-NC	↓

Note: UA = unaffected; NAE = no apparent effect; NC = not considered; NA = not applicable; ↑ = value of sign evaluation measure increases with increase in the value of independent variable; ↓ = value of sign evaluation measure decreases with increase in the value of independent variable; → = significant effect due to levels of independent variable (difficult to quantify); and alpha-numeric notation by arrow = study in which effects were observed.

Figure 4. Effect of driver familiarity on T_{used}.

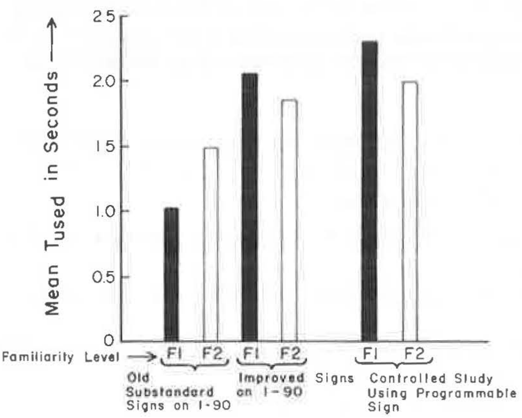
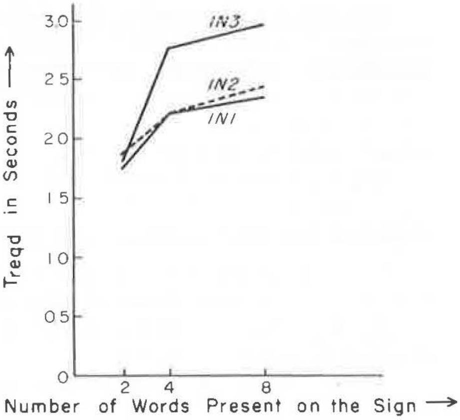


Figure 5. Minimum sign information acquisition time as affected by length of message and driver's information need.



The characteristics of good signs can, therefore, be briefly presented as follows: The value of T_{max} should be sufficiently high such that, for an unfamiliar driver, (a) the ratio T_{used}/T_{min} should be close to 1.0 (under higher visual loads); (b) the ratio T_t/T_{used} should be large, i.e., at least more than 3.0; and (c) the ratio T_{max}/T_f should be close to 1.0.

An increase in T_{max}/T_f indicates decreased use of the availability of the visual information displayed by the sign. Further, smaller values of T_t/T_{used} show increased concentration of the driver on the sign in his time-sharing process with the sign and other driving tasks. For an unfamiliar driver, a ratio T_{used}/T_{min} smaller than 1.0 indicates partial reading.

Because there exist intersubject and intrasubject differences in the sign-reading behavior of drivers, it is extremely difficult to make inferences about the adequacy of a sign just by observing data of one subject. Therefore, it is recommended that for the sign to be evaluated data on sign-reading behavior of many subjects be collected and, based on the characteristics of the distributions of the measures developed above, inferences on the "goodness" or "adequacy" of a sign be drawn.

From the distribution functions of the sign-reading behavior of a driver, the following estimates can be obtained in relation to certain preestablished values of criteria such as K_0^*, K_1^*, . . . , K_4^*:

1. Evaluation of information availability (estimate of the probability that $T_{max} \geq K_0$);
2. Evaluation of sign utilization and driver urgency (estimate of the probability that $T_{max}/T_f \leq K_1$);
3. Evaluation of the completeness of sign reading (estimate of the probability that $T_{used} \geq K_2^*$ (K_2^* can be selected as a suitable percentile value of the T_{min} obtained from the distribution of T_{min});
4. Evaluation of the time-sharing process (estimate of the probability that $T_t/T_{used} \geq K_4^*$);
5. Estimate of $K_3^* - K_4^*$, where K_3^* is the theoretically computed value on the estimate of the time-sharing process by the equation $K_3^* = (T_f - T_{emin})/T_{min}$.

In general, it can be stated that the higher values of the probability estimates described above indicate better effectiveness of the sign.

In this research the data on the sign-reading behavior of drivers under many different driving situations were obtained to gain an understanding of how the values of the sign-evaluation ratio are related to different variables involved in the problem of the evaluation of the signs. From such an understanding, the critical values of the variables K_0^*, K_1^*, . . . , K_4^* would be selected for both the evaluation and the design of a road sign so that the characteristics of the sign would be matched with the sign-reading behavior of the drivers under the traffic and highway situations existing in the vicinity of the sign.

Current highway signing standards presented in the Manual on Uniform Traffic Control Devices for Streets and Highways do not provide sufficient information to a highway engineer for designing highway signs. The design guidelines in such manuals only make a highway engineer aware of considerations such as use of safety factors to account for driver information and time associated with reading the sign.

Many of the findings of this research are still too exploratory in nature to provide quantified information on many such considerations, which are currently described merely as guidelines and have mathematical explicitness in the Manual on Uniform Traffic Control Devices. However, the findings strongly suggest that further research would lead toward the development of more mathematical and practical guidelines.

For example, some of the findings of this research offer solutions in the following directions in sign design based on sign-reading behavior of drivers:

1. This research has shown that, under normal traffic conditions and lower visual loads, the 50th percentile values of T_{max}/T_f lie in the neighborhood of 1.5; under higher visual loads (due to higher traffic density), the 50th percentile values of T_{max}/T_f tend to lie over 2.0. That result clearly indicates that, if the sign designer considered the driver's sign-reading behavior, he should not merely consider the legibility distances

but should take into account the factor T_{max}/T_f (obtained for the level of traffic density on the highway where the sign would be installed).

2. This research has shown that the time required by the driver to obtain informatic from the sign depends on factors such as length of message displayed on the sign and type of information need of the driver. Therefore, based on this research and future research in this area, some estimates of T_{min} and T_{used} can be provided to a highway engineer for better design of signs.
3. This research has also shown that drivers do not just concentrate on the sign to obtain information but share time with the sign and other objects. Therefore, standard values of T_i/T_{used} for different driving and signing conditions can be established for better design of the signs.

The discussions above were presented only for the purposes of illustration. It appears that a more complete and detailed implementation of this research would lead toward developing schemes and guidelines for both the evaluation and the design of road signs. Currently, further research in this area is under way at the Ohio State University to implement the results obtained in this research and to develop an operational tool that can be used by a highway engineer to solve the signing system design and evaluation problems.

CONCLUSIONS

Two major conclusions can be derived from the research. The first is that concrete proof has been provided to the research community that an eye-marker camera system is a valuable research tool among many other systems available today for the study of highway signing under actual driving situations. Second, the eye-movement data collected in this research have, for the first time, provided quantitative information on the driver's sign-sampling behavior. The data clearly show that, in general, drivers do not just concentrate on a sign (i.e., read a sign in one glance) but rather make several glances to it. The time-sharing process of the drivers with the signs and other objects on the road is found to be dependent on factors such as time-distance to first fixation on the sign, traffic density, type of informational need of the driver, length of message displayed on the sign, relevancy of information to the driver, and driver familiarity. Such data on sign-reading behavior of drivers under actual driving conditions were previously nonexistent. Further investigations into the results obtained in this study would no doubt lead to the development of better tools or assessment techniques for both the design and the evaluation of highway signs. Research in that direction is currently under way at the Ohio State University.

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REFERENCES

1. Bhise, V. D., and Rockwell, T. H. Development of a Methodology for Evaluating Road Signs. Systems Research Group, Ohio State Univ., Columbus, Final Rept. EES 315B, March 1972.
2. Bhise, V. D., and Rockwell, T. H. Strategies in the Design and Evaluation of Road Signs Through the Measurement of Driver Eye Movements. Presented at Annual Meeting of Human Factors Society, New York, Oct. 1971.
3. Davson, H., ed. The Eye. Academic Press, New York, Vols. 2 and 3, 1962.
4. LeGrand, Y. Form and Space Vision, Rev. Ed. Indiana Univ. Press (Millodot, M., and Heath, G., translators), 1967.

5. Rockwell, T. H., Bhise, V. D., and Safford, R. R. Development of a Methodology for Evaluating Road Signs. Systems Research Group, Ohio State Univ., Columbus, Interim Rept. EES 315B, June 1970.
6. Yarbus, A. L. Eye Movements and Vision. Plenum Press, New York, 1967.

DISCUSSION

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The research reported by Bhise and Rockwell represents an important innovation in highway safety research technology. Especially significant is the utility of the eye-marker camera system for evaluating a multitude of variables that may affect the availability or acquisition of guide-sign information. The authors have suggested that because eye movements are involuntary they are relatively bias free when compared to other driving performance parameters. Although some saccadic eye movement is relatively automatic and involuntary, eye-movement patterns seem to reflect a systematic sampling of environmental information, and the sampling is based on the driver's interpretation of incoming sensory information (7). This suggests that eye movements not only may be involuntary but also may be under the influence of current stimulus conditions and past experiences of the driver.

An additional point of some importance is related to the notion of using eye movements as the dependent variable in evaluating sign-reading behavior. It is quite apparent that frequency, pattern, and duration of eye movements reflect the impact of environmental, target, and subject variables on the information-search process. Therefore, it is reasonable to assume that eye movements provide an index of information availability. However, the relation of eye movements to the central information process of the driver is less clear. Thus, it would seem important to make a distinction between information availability and information acquisition. It seems logical to conclude that if an individual fixates on a guide sign the information contained on that sign will be available to him to the extent that it is legible and interpretable. One can be relatively certain that items have been acquired only if the driver is required to make decisions based on that information or if it can be inferred from his behavior that subsequent changes are correlated with informational input. In any event, eye movements constitute a critically important mediating process in the chain of events between the presentation of information and the response to it. Equally important is the authors' conceptual model of the components of this mediating process, their development of eye-marker system designed to provide meaningful data, and their development of the SEADEM program for analyzing the data.

In discussing the criteria of sign adequacy, the authors suggest that unused time should be as small as possible and that the ratio of the time of information availability to the time required by unfamiliar drivers to extract information from signs should be greater than or equal to the ratio of perceptual time sharing to the time that the sign information forms a reasonable image on the retina. Those criteria are appropriate given that sign adequacy is equated with the efficient use of information-display time. However, in concurrence with points made earlier, it is felt that such criteria would represent an extremely important but partial set of evaluative standards by which to assess the adequacy of signs. One must include measures of correlated decision-making and driving behaviors in order to have a complete picture of sign adequacy.

The results obtained by the authors are important in several respects. First, the relations between critical variables for highway research and information-search processes have been quantified by the use of a dependent variable that is unique in that it sensitively reflects both situational and psychological factors. For example, an examination of the summary table of results reveals that increasing the values of the situational factors of traffic density, sign angular location, and sign complexity generally has a negative impact on the sign evaluation measures; that is, available information is not used effectively. Likewise, as a driver becomes familiar with a roadway, he is less likely to attend to sign information. It is interesting to note that increasing the value of sign relevancy, driver urgency, and sign and legibility awareness is related to a more effective use of information. Those variables might well be classified as psychological. Location of sign, position of sign, and information need also seem to be correlated with the evaluation measures but are less amenable to interpretation. Those results would seem to suggest, as many earlier authors have pointed out, that psychological variables that affect driving performance have too often been ignored in design and evaluation of guide signs. This study clearly identifies the importance of those variables and provides a means of quantifying and evaluating them.

The second important aspect of the results is related to the specific utility of the various sign evaluation measures. As the authors have pointed out, T_f (maximum time-distance from which a driver actually begins to acquire reasonable information) is the key variable in evaluation and design of road signs because of its impact on the information-search process. T_{emin} (minimum time-distance from which driver can obtain information), T_{min} (minimum time necessary for the driver to obtain required information), and T_{used} (time during which a driver obtains or can obtain information from a sign) are also considered important variables because when used in various types of analyses one can determine how a driver utilizes the period of time in which the sign information is available to him. The authors then use those values to establish the characteristics of good signs. Stated verbally rather than in the ratio form used by the authors, the maximum time-distance during which the sign can form a reasonable image for an unfamiliar driver should be of such a value that

1. The amount of time spent fixating on the sign should approximate the minimum time required for an unfamiliar driver to extract the required information;
2. The amount of time spent fixating on the sign should be significantly less than the time required to perform other time-shared driving tasks; and
3. The time-distance of the first resolvable fixation should be the same as the time distance when the sign information can first provide a resolvable image.

Those criteria are critical and obviously related to the assumption that effective highway signs must perform their communication function with a minimal disruption of driving behavior. However, it might be desirable to assess the ultimate validity and reliability of those criteria in future studies by expanding the conceptual model to include various kinds of driving behavior that might serve as correlates of the visual behavior described in this paper.

In summary, the authors have developed an innovative and pragmatic method for the evaluation of highway guide signs. Future applications and refinements of the technique will undoubtedly serve to validate the logic of this approach. One is struck by the possibility of additional applications of such a model, and we shall be looking forward to reports of such applications.

REFERENCE

7. Lindsay, P. H., and Norman, D. A. Human Information Processing: An Introduction to Psychology. Academic Press, New York, 1972.

Donald A. Gordon, Federal Highway Administration

The Bhise and Rockwell paper represents an important piece of research. The eye is the point of entry of most information from the highway environment. The visual stimulus is the initial incident in the chain of events that leads finally to the driver's steering and braking reactions. We are, therefore, fortunate that during the past 4 or 5 years, Rockwell and his associates at Ohio State University have concerned themselves with studying the driver's eye fixations. That is no easy task, as those of us who have tried to record eye movements in the accelerating and jolting car can attest. In the latest phase of their work, Bhise and Rockwell have applied eye-registration techniques to the evaluation of signs. Their paper presents the findings of this phase and comprises results of 8 field and 3 laboratory studies.

BASIC CONTRIBUTIONS OF EYE-MOVEMENT STUDIES

Before discussing the contributions of this work to the evaluation of signs, I would like to mention some of the basic findings. In developing their assessment tool, Bhise and Rockwell first had to understand how the eye operates in obtaining road information. The basic factors that affect eye movements had to be taken into account in interpreting the results.

Eye-movement studies by early investigators, such as Javal, Dodge, and Judd, go back almost a hundred years. Those studies showed that the eye does not move in a continuous sweep as it seems to the viewer but rather exhibits long fixations interrupted by short saccadic (jump) movements of about $1/20$ sec. The fixations last about $1/2$ sec each. The early studies also showed an amazing compensation by the viewer's eye for head movements and time-phased movements of convergence and divergence. I mention this early work because the findings of eye-movement studies have always been fascinating and somewhat unexpected.

Bhise and Rockwell's basic contributions concern the effects of driver and sign characteristics on eye movements. They have shown that eye fixations reflect the driver's familiarity with the sign, his trip purpose, the relevance of the message to the driver's goal, the redundancy of the signs, and the size of the sign letters. Some of their findings are given to illustrate the novelty of this work:

1. Although drivers spend more time viewing a sign whose message is relevant, nonrelevant guide signs are also fixated. The authors show that the majority of freeway guide signs are actually looked at by the driver as he passes.
2. The driver spends more time viewing a sign when the information he is looking for is absent than when it is present.
3. The driver starts to view the sign relatively later when traffic is heavy than when traffic is light. His fixation is also delayed when he is closely following another vehicle.
4. If the driver gets relevant information from an advance warning sign, he spends less time viewing subsequent signs than he would otherwise.
5. Although the driver spends less time scanning a familiar sign than an unfamiliar sign, the difference in times is less than one might expect.
6. The driver sometimes takes less time than he needs in viewing the sign. The comparison is with minimum times found in laboratory studies of sign viewing.

These are some of the basic findings of these studies. Earlier phases of this work were concerned with fixations during the process of learning to drive and with the effects on visual fixations of alcohol and fatigue. The virtue of all the work is that the conclusions flow from and are supported by quantitative performance data.

APPLIED CONTRIBUTIONS

The main purpose of these studies was to develop a method of evaluating signs. To do this, the authors evolved a set of measures of the efficiency with which information was obtained from the sign. Those measures are based on time relations. T_{max} is the point in time at which the sign can first be read; T_f represents time at which the driver first fixates the sign; T_t is the total amount of time available to the driver for viewing the sign; and T_{max}/T_f is the relation between the time at which the sign can first be seen and the point in time at which it is actually fixated. A full description of those and other evaluation indexes is given in the report itself. Predictive equations were programmed on the computer to indicate trade-offs among the factors affecting readability. The number of messages, letter size, and sideward positioning of the sign may be mutually arranged to reach a level of adequate readability.

Bhise and Rockwell state that a bad sign is shown by several symptoms: (a) The first fixation occurs much later than necessary, (b) the sign receives an excessive amount of attention, and (c) the sign receives attention even when the driver is very close to it. These symptoms are defined in terms of fixation times. Although it may seem intuitively evident that those measures indicate sign pathology, one would feel more comfortable if their validity was experimentally demonstrated. For example, the contrast of a sign may be systematically decreased. In this case, the eye-fixation times should show more and more pathological symptoms, thus indicating the validity of the symptoms. One also wonders how driver unfamiliarity would affect eye movements. A novel sign, such as an unusual diagrammatic design, will invite a long visual inspection whether or not it is a good sign. Driver unfamiliarity may be overcome in the laboratory by special training on a set of signs similar but not identical to the test signs. It is much more difficult to give this sort of training on the road.

Although eye-fixation techniques are a valuable addition to sign evaluation methods, there are other methods. Signs have been evaluated by Roberts, Kohlsrud, and others in terms of erratic maneuvers. Berger, Gordon, and Zajkowski separately have used a laboratory technique to assess signs. The driver was shown retouched highway pictures that had experimental signs added. He was asked to state as quickly as possible the lane he should be in to reach an assigned destination. That technique provides measures of the time required to extract information from the sign and indications of the correctness of the driver's interpretations as shown by his lane choices. Another assessment technique developed by Mace, Hostetter, and Seguin and perfected by Mast, Hooper, and Chernisky involves projecting signs on a screen in front of the driver. Fictitious signs and exits are used to prevent the effects of driver familiarity. The driver's reaction time, vehicle speed, and acceleration noise are measured by that technique. There are also operational indications of sign failure: drivers stranded on the gore and shoulder of the road and letters of complaint from frustrated motorists. I mention these methods because they seem to have been overlooked or at least not referred to by Bhise and Rockwell. On the other hand, eye-movement techniques for evaluating signs have important potential advantages. They can be carried out in the operational setting, and they involve the visual mechanism by which drivers obtain and use road information.

The Bhise and Rockwell studies raise a number of challenges for all of us, and I think for the authors too. So far, Rockwell and his coworkers in the United States and Keith Rutley in England have been almost the only ones involved in eye-movement work. Many more of us would be involved if we could use the equipment or, better yet, if a simpler registration device was developed. Present methods are fussy and uncomfortable and require the attendance of a trained technician. A number of questions remain to be answered. Are the performance measures so far proposed the most effective for assessing a sign? How do the eye-movement results check with other sign-testing methods or combine with other methods to provide a complete evaluation? What other vehicular-guidance problems can be effectively approached with eye-fixation techniques? There is also need for further review of the work already accomplished. After completing their large-scale program of 11 studies, Bhise and Rockwell must feel a bit by themselves and appreciative of whatever feedback is offered by the traffic engineering community. Novel methods of improving roads and signs do not so often appear. When one does, it benefits us to pay attention and give it a fair and thorough hearing.

Fred Hanscom, Virginia Highway Research Council

The authors are to be commended for an important effort in which they examine some meaningful parameters in relating motorists' performance to highway-signing characteristics. The problem of matching signing with driver behavior is, without a doubt, representative of one of the most critical research needs in the area of motorist information systems. The variables explored in this paper provide much insight relative to driver sensitivity as an optional method to evaluate highway signing; yet, the research should be considered as a basis for an evaluation methodology rather than a completely operational tool.

The focus of this discussion will be on some ideas relative to the integration of eye-marker camera research into the development of sign evaluation methods. Some specific recommendations that relate to work presented by Rockwell and Bhise will be given first, and then some general concepts will be presented evolving from other signing research in light of potential refinements using eye-marker camera techniques. The intent will be to provide some impetus for incorporating advanced human-factors technology into eye-marker camera research.

Although the authors have alluded to many essential considerations, their work still does not constitute a workable tool for the evaluation of highway signs. The presentation of the research for practical interpretation by a traffic engineer should define various driver task-loading situations indicative of different levels of driver attention sharing between the sign-reading tasks and other necessary driving tasks. Various task-loading situations should be delineated according to various levels of traffic density, highway geometry, weather, and similar non-signing-related parameters. Then, for purposes of providing a practical traffic engineering tool, it would be desirable to prescribe signing requirements in terms of maximum number of signs for a given highway section, sign content as a function of information loading, and the like for each of the previously delineated driver task-loading situations.

However, the accomplishment of those steps would involve considerably more research than has been done to date. An interim approach, based on data already collected, could be to provide practical "engineering" guidelines for T_{max}, K_t^*, and other variables as a function of the already observed sign content and driver task loading.

A key to future incorporation of eye-marker camera techniques in the evaluation of highway signs rests in the researcher's ability to define and analyze the driver's information-seeking task. Research by King and Lunenfeld (8) has provided much insight relative to motorists' satisfaction of their information needs. Their analysis of the driving task disclosed that the operations performed by a driver can be characterized in terms of a hierarchy. The basic tasks of tracking and speed control (called microperformance) are at one end of the hierarchy; driver responses to road and traffic situations are in the middle; and direction finding and trip planning (called macroperformance) are at the other end. Driver information needs were also seen to be related to this hierarchy. It was found that a demanding priority exists in satisfying information needs; microneeds have priority over situational and macroneeds. Satisfying this priority of information needs was said to be basic to the design of a motorist information system.

The systematic approach to the information-seeking process of drivers opens the door to some interesting applications of eye-marker camera research. Of particular interest could be the situation where information at all 3 levels is competing for the driver's attention. Driver response to each of the performance levels can be quantified; hence, verification of the Lunenfeld and King research would be available. Further, a closer examination of the driver attention-sharing trade-offs among the control, guidance, and navigational tasks would be a valuable asset in the development of a sign evaluation criterion.

In a recent follow-up article, Alexander and Lunenfeld (9) asserted that traffic engineers should use the time-sharing trade-offs to locate navigational information at a place where the guidance task is not so complex that low-primacy information cannot be processed. Through use of eye-marker camera techniques and related research, a quantification of the guidance task for a given section of highway could allow a determination of the optimal placement and content of navigational information that a motorist could process. However, the determination of driver task loadings may be difficult for a number of reasons that impose limits on the interpretation of eye-marker camera data. First, spare driver visual capacity often results in eye fixations on irrelevant information. Second, it is difficult to account for the effects of peripheral or extra-foveal vision. A measured fixation may merely represent a meaningless point of focus while the motorist is peripherally acquiring significant information. Finally, there is the problem of a motorist looking at an object but not processing the information.

Although such problems are no doubt inherent in eye-marker camera research, some of the existing difficulties can be resolved with continued effort. One such difficulty, which was cited in an earlier work by Rockwell (10), is that of accounting for intersubject differences resulting from varied idiosyncratic perceptual characteristics of drivers. This problem denotes the obvious need for refined human-factors techniques to be combined with eye-marker camera research.

An interesting approach to provide some insight relative to individual driver difference in perception of highway signs might be the application of "expressive self-testing" principles that have recently been researched by Roberts et al. (11). Their work has demonstrated that certain motivational and attitudinal differences between individuals, which are detectable through questioning techniques, can be used to predict certain biases affecting many motorists' decisions. Of particular interest is the capability of the technique to show differences in perceived danger in a driving situation between groups of high versus low self-testers. The use of that method or related psychological techniques may help explain some of the individual differences that confound the interpretation of eye-movement data.

There is an urgent need to develop more sensitive techniques to evaluate highway signing. The recent acceptance of graphic-signing concepts makes this need more apparent. Current evaluation techniques such as conflicts studies and erratic-maneuver analyses do not provide insight into driver decision-making processes. The authors have provided a significant advancement in the complex process of providing a human-factors approach to determine the impact of signing on the motorist. Suggestions for future research outlined in this discussion include revising the format of the evaluation technique to provide signing standards as a function of driver task loading; using eye-movement data to quantify various components of the driving task; and combining eye-movement results with psychological testing to partially resolve intersubject perceptual differences.

REFERENCES

8. King, G. F., and Lunenfeld, H. Development of Information Requirements and Transmission Techniques for Highway Users. NCHRP Rept. 123, 1971.
9. Alexander, G. J., and Lunenfeld, H. Satisfying Motorists' Need for Information. Traffic Engineering, Vol. 43, No. 1, Oct. 1972.
10. Rockwell, T. Skills, Judgment and Information Acquisition in Driving. Human Factors in Highway Traffic Safety Research (Forbes, T. W., ed.), 1972, Ch. 7.
11. Roberts, J. M., Hutchinson, J. W., and Carlson, G. S. Traffic Control Decisions and Self-Testing Values: A Preliminary Note. Traffic Engineering, Vol. 42, No. 11, Aug. 1972.

ROADSIDE DELINEATION CONCEPTS: A NATIONAL STUDY

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The need for national, uniform designs and applications of roadside delineation has long been recognized by traffic authorities. A comprehensive study was, therefore, undertaken to obtain a better understanding of present practices of roadside delineation and to further establish criteria for the selection of an optimum roadside delineation treatment at a given condition. In this study, an extensive literature review and a national survey of all state highway departments were conducted to form a state-of-the-art summary of roadside delineation concepts. Attempts to formulate a uniform selection process for roadside delineation treatments involved discussions of evaluation criteria and presentation of a suggested selection program. The results of this study provide updated and thorough knowledge of existing and proposed roadside delineation techniques.

•WHAT is it that causes night driving to be so hazardous? It has been found that more than 50 percent of night accidents can be directly attributed to poor roadway visibility. A large percentage of all night traffic accidents are single-car accidents that occur when the vehicle runs off the road. Those accidents are the result of complex interactions among vehicle design, visibility, and other design characteristics of the roadway.

Daylight delineation of the roadside can be accomplished with reasonable satisfaction by using currently available materials and methods. Night roadside delineation, however, requires an entirely different approach and frequently leaves much to be desired. Reflectorized materials of various types have been used with considerable success. Those materials best serve their intended purpose when properly placed. Even when properly placed, many of the present materials will not function adequately on a wet night.

The two most common forms of roadway delineation are the post-mounted delineator and the pavement-level markings with paint or raised pavement markers. Post delineators of various forms have gained wide acceptance throughout the country as a roadside delineation treatment. This treatment has been recognized by the Joint Committee of the Institute of Traffic Engineers, Federal Highway Administration, and American Association of State Highway Officials. As a result, the use of delineators is authorized in the Manual on Uniform Traffic Control Devices (MUTCD) (22). The popularity of post delineators is undoubtedly due to their effectiveness both at night and during inclement weather when painted markings are ineffective.

Many reflective materials are available for increasing roadway visibility, but there is limited information concerning the effectiveness of these materials. In recent years, most of the highway delineation studies have been directed toward the physical efficiency of the materials themselves. Yet, one of the greatest needs is to specify effective uses of reflective materials. The effective use of roadside delineators depends on a number of variables such as the type of material, its self-cleaning ability, the durability of the device, the maintenance cost, and the rate and methods of application. Because guidelines do not recommend a standard installation, many highway agencies do not get optimum results from roadside delineation devices.

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Traffic safety is linked directly to visibility. When a motorist has good visibility, he will also have good roadway definition. Conversely, if good roadway definition can be provided, better visibility will be realized, and that in turn should result in a reduced accident rate. Adequate visibility requires that delineators be correctly placed and illuminate efficiently. A delineation technique must be effective under all conditions, including rain and fog at night and during the day. The delineator must retain visibility under conditions of typical wear, deterioration, and dirt buildup.

The warrants and the practices regarding the application of roadside delineators vary widely among states, even among districts within a state. Delineators have been applied without regard to national standards, particularly on roadways that possess one or more of the following characteristics: metal guardrail dividers, fences mounted on raised concrete or blacktop dividers, reinforced concrete wall dividers, center island dividers with curbing, entrance and exit ramps, bridge abutments, lampposts, and road edges. These all pose a potential hazard to the driver especially since the speeds on such highways are in the 40- to 70-mph range.

STUDY OBJECTIVES

The primary objectives of this study were to review current delineation techniques, define current needs, and stimulate research and development to improve the present roadside delineation. The specific objectives of this study were to review past and present practices of roadside marking delineation, establish a standard set of criteria for the selection of roadside delineation techniques, and suggest a simple yet thorough procedure to help determine optimum roadside delineation treatments for given conditions.

PROBLEM OF INTERESTS

A literature review of the state of the art of roadside delineation techniques produced some very interesting findings. The pertinent information is summarized as follows:

1. No nationally accepted technique has been developed to evaluate the effectiveness of roadside delineation techniques;
2. Although a wide variety of raised pavement markers is being used, no single marker has been developed that is suitable for both day and night use;
3. The state highway departments do not devote particular attention to delineation but generally handle it as a part of their overall operations (the delineation task force in California is an exception);
4. Post delineators provide good advance delineation at night, especially during inclement weather, but there are questions concerning their placement with respect to curves; and
5. Driver information is a principal part of delineation treatments and falls into 2 areas—advance delineation to clearly define the driver's path and near delineation to aid the driver in his lateral placement.

NATIONAL QUESTIONNAIRE SURVEY

An opinion survey was conducted to determine more accurately the existing state of the art of roadside delineation. A survey questionnaire (Fig. 1) was sent to all state highway departments, the District of Columbia, and Puerto Rico. Of the 52 questionnaires distributed, 49 were returned. The intent of this survey was to gain a thorough knowledge of current roadside delineation practices and especially to obtain an insight into new delineation techniques. Emphasis was placed on the raised pavement marker and the post-mounted delineator. Also of importance in the survey are the comments of the highway departments with respect to the policies in the MUTCD concerning these markers. Increasing interest in the possible use of a pavement edge marker has created questions concerning the existing policies of height and placement of roadside delineators and has suggested modifications for uniformity and new delineation techniques. This survey presents the current opinion of highway departments in this area and trends related to roadside delineation.

Figure 1. Roadside delineation questionnaire.

1. Which of the following roadside delineation techniques do you most commonly employ?
   - ( ) Post-mounted delineators
   - ( ) Raised Pavement-edge Markers
   - ( ) Contrasting Shoulders
   - ( ) Lighting
   - ( ) Painted Curbs
   - ( ) Indirect Methods, i.e. trees, etc.
2. List any new methods and/or materials of roadside delineation in addition to the above which are employed by you.
3. What, if any, are the dominant factor(s) in the above choice(s)?
   - ( ) Type of roadway
   - ( ) Traffic condition of roadway
   - ( ) Physical condition of roadway
   - ( ) Economic
   - ( ) Other (please specify)
4. The revised Manual on Uniform Traffic Control Devices, MUTCD, states that "delineators should be placed at a constant distance from the edge of the roadway" and spaced from 200 to 528 feet apart. "They shall be placed not less than 2 nor more than 6 feet outside the face of the curb or the outer edge of the shoulder..." Are you in agreement with this policy of delineation placement and, if not, what do you think would improve it?
5. By having a delineator at pavement level, it would be affected by both high and low headlight beams and also keep the driver's attention on the actual pavement edge rather than some four feet above it. If a maintenance problem incurred equal to or less than present delineator maintenance costs, would you accept a lower roadway delineator if it were available?
6. What is your practice for delineation along limited access highways with respect to:
   - (a) Metal guardrail dividers
   - (b) Fences mounted on raised concrete or blacktop dividers
   - (c) Reinforced concrete dividers
   - (d) Center island dividers with curbing
   - (e) Entrance and exit ramps
   - (f) Bridge abutments
   - (g) Lampposts
   - (h) Road edge
7. The revised MUTCD specifies a minimum 4 foot height for post delineators. Are you in agreement with this standard? If not, what alteration do you suggest?
8. Do you feel that delineators have value in lighted sections?
9. An expressed opinion on this topic will be greatly appreciated.

The first question of the survey related to current roadside delineation techniques and their employment by the state highway departments. The results are as follows:

Technique	Percent
Post-mounted delineators	93
Raised pavement edge markers	30
Contrasting shoulders	5
Lighting	42
Painted curbs	49
Indirect methods	3

The highway departments were also asked to indicate any new roadside delineation methods or materials or both in addition to those mentioned in the questionnaire. The following states reported additional techniques:

State	Technique
District of Columbia	Barricades, flex-posts
Idaho	Snow poles
Nebraska	Pavement grooving
Pennsylvania	Experimental raised pavement markers

State	Technique
Kentucky	"Codit" reflective paint
Utah	Flexible post delineators
Wisconsin	Flexible (spring and plastic) delineators

The highway departments were also asked to indicate the dominant factors considered in the selection of roadside delineation techniques. A summary of those factors and the order of their relative importance follow:

1. Type of roadway,
2. Traffic conditions of roadway,
3. Physical conditions of roadway,
4. Economic considerations,
5. Ambient conditions, and
6. High accident locations.

Two questions concerned specifications in the MUTCD and whether the state highway departments were in agreement or would accept substantiated modifications. With respect to the placement of the roadside delineators, 63 percent of the states agreed with the present standards, 5 percent disagreed, and 32 percent partially agreed. In regard to the acceptance of a lower delineator of the post-mounted type, the following conclusions were obtained: (a) 47 percent accepted the lower delineation, if the maintenance cost incurred is equal to or less than the existing cost; (b) 34 percent would not accept the new delineation technique; and (c) 19 percent partially accepted the technique and requested more information.

The question associated with the 4-ft delineator height closely parallels the previous question but puts more emphasis on delineator height standards. Of those returning questionnaires, 84 percent agreed with the present standard and 16 percent disagreed.

Responses to the question about the effect of delineators in lighted sections were extremely varied. Of the 49 states returning questionnaires, 23 or 47 percent stated that the delineator definitely has value in a lighted section, 14 or 29 percent disagreed, and 12 or 24 percent partially agreed. The major criticism arose from the fact that most highway departments felt that delineators lose their effectiveness in a lighted situation. The typical agreement and disagreement comments are respectively as follows:

> Delineators assist and guide motorists in the lighted section during daylight hours as well as at night and during adverse weather conditions. The delineators are dependable and a great aid to motorists.
>
> We do not feel that delineators have sufficient value on lighted sections to be worth their expense. Failure of the entire lighting system is so rare that delineators serve little useful purpose. Delineators tend to prevent vehicles from pulling far enough off the highway when an emergency stop is made.

This policy inconsistency of the highway departments warrants future consideration and research aimed at standardizing a policy.

Question 6 attempted to ascertain how the various state highway departments employ delineation with respect to specific roadside hazards. Eight specific hazards were listed in the questionnaire, and the following are the reported techniques of delineation for each hazard:

Technique	States
Metal guardrail divider	
Post-mounted delineators	14
Reflective tab inserts	11
Edge line striping	6
No practice	11
Fences mounted on raised concrete or blacktop dividers	
Post-mounted delineators	4
Edge line striping	4
Reflective tabs	3
No practice	26
Reinforced concrete dividers	
Hazard markers	9
Edge line striping	5
Reflective paint or tape	3
White slurry concrete	2
No practice	21
Center island dividers with curbing	
Painted curb	20
Post-mounted delineator	11
Edge striping	10
No practice	6
Entrance and exit ramps	
Post-mounted delineators	23
Painted edge line	12
Raised pavement markers	12
Bridge abutments	
Hazard marker	34
Post-mounted delineators	8
Reflective paint	3
Lampposts	
Reflective paint	2
Breakaway units	1
No practice	38
Road edge	
Painted edge line	39
Post-mounted delineator	26

This survey of roadside hazards clearly revealed a need for improved roadside delineation practices. The number of states reporting no practices for the marking of the hazards warrants further studies if the national roadway system is to be made safer.

UNIFORMITY OF ROADSIDE DELINEATION

The MUTCD sets forth the basic principles that govern the design and usage of traffic control devices including roadway delineation. The manual gives the design, application, placement, and maintenance of the delineators and strives to creat uniformity. The application of delineation devices along highways and streets is desinged to communicate either desired or needed information to motorists to help them pass over the particular section of highway safely and expeditiously. There is another reason for stressing uniformity. If similar situations on the highway are treated in the same manner, drivers can see, recognize, and understand the delineation treatment quickly.

The selection and the use of roadside delineators have become a challenging task. To be successful, delineation programs must be administered by trained engineers.

As the result of the literature review and national questionnaire survey, two sections of roadside delineation in the MUTCD have come under question.

Delineator Placement

The first area of question concerns the placement of roadside delineators, especially post-mounted delineators. The MUTCD presents the following specifications:

> Delineators, if used, shall be mounted on suitable supports so that the top of the reflecting head is about 4 feet above the near roadway edge. They shall be placed not less than 2 nor more than 6 feet outside the outer edge of the shoulder, or if appropriate in the line of the guardrail.
>
> Normally delineators should be spaced 200 to 528 feet.
>
> Spacing should be adjusted on approaches and throughout horizontal curves so that several delineators are always visible to the driver.

Many state highway departments are generally in agreement with the above policies; yet, there are some who feel that the policies should be modified. In the questionnaire, the state highway departments were given the opportunity to express views on these policies, and the following responses were received:

> Arizona: We concur with the main-line placement, but we do not concur with the policy of placement of delineators on ramps. We feel that a maximum spacing of 200 ft should be allowed.
>
> Maryland: Spacing along road should be more specific.
>
> Montana: We specify a minimum distance of 15 ft from centerline to delineator. This allows for snowplowing and wide loads on narrow roadways.
>
> Ohio: Delineators are spaced 200 ft on tangent sections and are spaced on horizontal and vertical curves so as to make 5 delineators visible ahead of the driver.
>
> Tennessee: Disagree with the policy because it provides a range of spacing between delineators and a range in the spacing from the edge of the roadway. The motoring public is best served when we provide them "constants" on which they can develop conditional responses.
>
> Minnesota: We would consider a maximum lateral limit of 7 or 8 ft reasonable; that would avoid conflict with our snowplowing operations without reducing delineation effectiveness.
>
> Wisconsin: We have been placing delineators 200 ft apart, but experience indicates that it would have been better had we started placing them 20 to the mile. We lose quite a few which are placed 2 ft outside of the shoulder but feel that they should not be placed farther away from the roadway because their effectiveness decreases rapidly as they are moved out.
>
> Illinois: Should be placed a minimum 2 ft outside the curb or usable shoulder or in line with the face of the guardrail.
>
> Idaho: The Idaho Department of Highways supports the basic standards set forth in the MUTCD. However, it is felt that allowances should be made for some flexibility to permit deviations such as snow poles. The delineator spacing on horizontal curves set forth in the MUTCD results in too many delineators.

Those comments reveal that the principal criticisms of the policy deal with the range of values presented by the MUTCD. It appears that the spacing for delineators would satisfy most departments with respect to main-line placement but that present standards for horizontal curves and ramps are adequate. Placement of delineators 15 ft from roadway centerline and approximately 250 ft apart on the main line appears to be an acceptable compromise.

The extended distance between the delineators reduces the number of delineators per mile, does not sacrifice effectiveness, and reduces overall installation cost. The distance, if accepted nationally, would standardize delineator spacing and provide a "constant" for the road user. This constant would allow the driver to judge his speed at night without taking his eyes from the roadway by repeated glances at the speedometer. In time, the road user would develop a conditioned response to the placement of delineators and thus gain driving security. A more secure driver performs better and would be able to achieve the highest as well as the safest level of service of the delineated road.

This modification would also provide for the uniformity of specifications within the MUTCD and make it more acceptable to all state highway departments. The altered policy could be supplemented with another policy stating that engineering judgment and personal experience can be and should be employed in any questioned situation. That would allow states to handle special delineation problems in their locality. Furthermore, it would be more in line with the true purpose of the MUTCD and the manner in which it is to be employed.

Delineator Height

The second area of question concerns the policies of the height of roadside delineators. The present policy specifies that "delineators, if used, shall be mounted on suitable supports so that the reflecting head is about 4 ft above the near roadway edge." That policy is in conflict with one given in the Interstate Manual, which specifies a 3-ft height.

The rationale of the present specification is that delineators placed lower than 4 ft above the pavement surface are quickly rendered ineffective by "road splash" and film from passing vehicles. A delineator is supposed to indicate to the driver where the pavement bounds are located and the direction of the roadway. However, it is felt that the present delineators located in a plane 4 ft above the pavement give the driver a false impression of the roadway edge and do not satisfy the driver's 2 major needs:

1. A progression of delineators to best accentuate the contour of the road ahead of the driver's perspective; and
2. A device low enough in profile and close enough to the road to be seen clearly when the driver uses the low-beam headlights.

To a large extent, information required by the driver in roadway situations is a function of the reasons that dictate the requirement of roadside delineation treatments. Therefore, delineators define the vehicle path more effectively if placed lower to the ground, for then they are directly associated with the roadway. A delineator placed at roadway level more accurately informs the driver of the actual pavement edge and also keeps the driver's eyes on the roadway. Eye-motion studies indicate that drivers tend to look down the road to check for other vehicles and roadway hazards and then view the pavement center or edge for lateral placement guidance. During night driving, the opportunity for long-range forward vision is reduced, and the short-range vision in front of the vehicle and on the sides of the highway lane receives more emphasis, especially when the road is curvy and other vehicles are not present.

The questionnaire also asked the state highway departments how they felt toward the employment of a road edge delineator if it were available and cost no more than present delineators. Some of the constraints placed on the delineator, if accepted, are as follows:

1. It must not interfere with snowplowing;
2. It has to withstand road splatter;
3. It should be readily visible in inclement weather; and
4. It should supplement present techniques.

Existing road edge pavement markers meet most of these constraints, yet they still have a major shortcoming. They improve roadway delineation in wet weather, but do they cause drivers to drive faster than the roadway surface conditions warrant? Several states seem to think that is the case but do not have workable solutions to the problem, excluding actual enforcement or driver education. In addition, because of the wide variation of climatic conditions, it may be improbable that the same delineation device employed by certain states can also be used in others with the same degree of effectiveness. For example, a low-level delineator could readily be employed in most southern states but would not be practical in extreme northern states because of the excessive snow accumulations. Therefore, the idea of uniformity on a national level would have certain limitations that must be considered before it is adopted.

One of the questions concerned the acceptance of a lower delineator of the post-mounted type, and the following responses were obtained:

Response	Percent
Accept the lower delineation if a maintenance cost incurred is equal to or less than the existing costs	47
Would not accept the new delineation technique	34
Partially accept the technique and request more information	19

The question associated with the 4-ft delineator height closely parallels the previou question but puts more emphasis on delineator height standards. Of the returned questionnaires, 84 percent agreed with the present standard and only 16 percent disagreed.

New Delineator Concepts

The existence of a pavement level delineator with the characteristics already mentioned is not totally unrealistic. Experimental markers exhibiting even more advantag are under study and need only extensive acceptance to be readily employed. The Texas Highway Department has undertaken this challenge and has used pavement level delineators in their roadside delineation program. Its comment on this practice is as follows:

> Reflectorized pavement markers, which amount to a delineator at pavement level, are now being used extensively and do serve a definite purpose. They do a better job of delineating the intended path of a vehicle than do roadside delineators but being located at the pavement level are not visible for nearly as great a distance. Maintenance problems on the two are about the same; both are vulnerable to traffic and require considerable maintenance mostly in the form of replacement. A combination of the two types of delineation is probably most effective depending on the alignment of the roadway and the intricacies of the vehicle paths to be delineated.

The Florida Department of Transportation expressed its opinion as follows:

> Although the pavement delineators are a very helpful device, we do not feel that the present type is the ultimate answer. The cost and maintenance are too high. Several research projects are underway now to find a better system of pavement delineation, and it is hoped that they will overcome the problem of wet night reflectivity.

The experimental markers use the principle of light reflected from the sun and from automobile head lamps and are designed to give the drivers a safer guidance route along increasingly extensive and complicated highways. Those delineators, when placed at close intervals on the very edge of the road, provide the driver with a continual stream of sensory data. Therefore, while the driver can receive through his peripheral vision an uninterrupted picture of the exact contour of the road edge, he can also keep his eye on the traffic. The device can also aid in helping the driver judge relative speed when either there are no indicators on the highway or the ones passed are unevenly spaced. A driver can sense and measure his speed by observing the rate at which evenly spaced indicators appear to pass by. Sense of speed can become conditional, and indecision ca be eliminated in high-speed traffic if the interdelineator spacing is properly varied to give the driver reflected stimuli at a rate that he can interpret from experience to be above or below the reasonable speed for that section of highway.

DELINEATION DESIGN METHODOLOGY

A means of correlating principal parameters to determine the optimum roadside delineator to install on a roadway or to supplement already existing delineation is essential in improving roadway visibility at night. A simple yet thorough procedure is neede to aid in the selection of adequate delineation techniques with respect to certain basic criteria. Figure 2 shows a decision-making process that may readily be employed for delineation selection based on specific criteria.

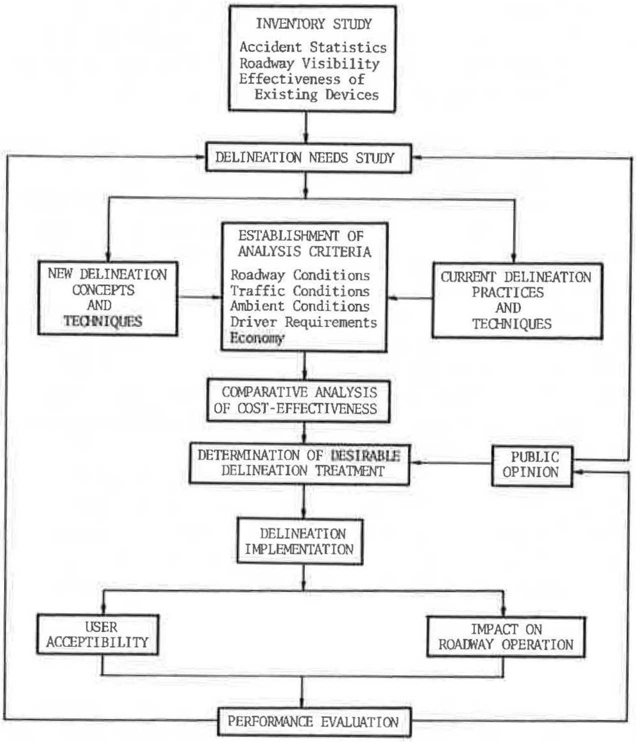
Inventory Study

Numerous roadway characteristics can be shown to be grounds for initiating this process although there are 3 principal ones: frequency and type of accidents, level of roadway visibility, and effectiveness of existing devices. Accidents receive the greatest emphasis and provide the grounds for many highway delineation needs studies. Many single-car accidents in which the vehicle leaves the roadway are attributed to the fact that the driver did not know where the roadway actually went. Roadway level of visibility, particularly during the night, is another means of determining the need for a roadside delineation improvement study. Improved roadway visibility through the use of delineation devices can create an increase in speed and thus a reduction in travel time as more drivers are able to safely identify the road contour and gain a more secure and confident feeling as they travel over the delineated roadway. Another characteristic considered in the inventory study is the effectiveness of the existing roadside delineation devices. The investigating agency studies the existing system and attempts to determine its deficiencies, if any. Once completed, this effectiveness study, joined with the accident and roadway visibility studies, will form the basis for a comprehensive delineation needs study.

Needs Study

The objectives of a needs study can also be simply stated: to formulate a broad plan for the orderly development of the delineation system as a whole, to provide a basis of adequate and systematic financing of the delineation system, and to provide a basis for

Figure 2. Roadside delineation evaluation.



coordinated improvements to all related systems. The needs study results not in an installation program but rather in cost estimates and long-range plans on which annual implementation programs can be based. Its basic goal is a macroscopic picture of total need during a period of years from which a financial program can be arrived at and a construction program can follow.

Each state conducting a delineation needs study should devise its own organization and procedures. Many states set up through legislative action a special agency or commission to conduct the needs study; other states have their highway departments conduct the study. However, a comprehensive delineation needs study requires the full cooperation, assistance, and understanding of all governmental units responsible for highway safety.

Public opinion should also enter into the highway delineation needs study as an indirect result of the performance evaluation of the current delineation technique. The public reaction to the delineation system in use provides the nonprofessional attitude, which is a fundamental part of a well-rounded study. The views of motorists with respect to the system provide the engineer with input that can be effectively used to aid in the development of delineation systems. That will gear the study more closely to actual driver requirements. Coupled with the technical performance evaluation, the public opinion of the implemented system creates a complete picture of the actual needs of the highway and its users.

Two important aspects in the needs study are financial and technical. The financial study incorporates items such as material costs, installation costs, replacement costs, and maintenance costs. The technical study determines what is actually required to delineate a roadway section or to supplement an existing delineated roadway section. The work required leads directly to a thorough review of both new delineation concepts and current delineation practices and techniques.

Analysis Criteria

Once various delineation concepts and techniques have been thoroughly reviewed, a cost-effectiveness analysis is then carried out. That analysis is preceded by the establishment of criteria for evaluating delineation systems. The principal criteria are roadway conditions, traffic conditions, ambient conditions, driver requirements, and economy. Those characteristics give a complete view associated with the delineation requirement and form the basis for sound engineering judgment in the selection of the delineation system.

The characteristics of roadways are the first logical considerations to be encountered in this analysis. The direction of the traffic (1-way or 2-way), lane width, lateral clearance, and location of weaving areas and ramp terminals all should be considered. In like manner, operating speed, roadway capacity, and demand volume must be also analyzed. Ambient conditions relate primarily to weather and include measures, such as clear, dry, cold, warm, hot, rain, snow, fog, smog, smoke, wind, and wet or icy pavement, that affect the ability of a roadway to accommodate traffic and, thus, are important considerations in an analysis of a delineation system. Moreover, to be able to select the delineation treatment under various conditions, one should also know the minimum as well as the optimum visual information needed by the driver. If "adequate" information is available to the driver, proper driving behavior with respect to roadway conditions should be evident. The information received by the driver must allow him to act on the information under various circumstances. In addition, the delineation treatment must be economically feasible. Of the many costs to be considered in the analysis, those that appear to constitute the largest percentage are material costs, installation costs, maintenance costs, replacement costs, and costs attributed to accidents. The cost analysis usually is the most important and has the greatest weight in determining the final choice.

Cost-Effectiveness Analysis

Once the factors of the analysis criteria have been established, a cost-effectiveness analysis is undertaken. A cost-effectiveness analysis describes benefits and costs as a function of different levels of achievements and effectiveness. The delineation techniques are compared through trade-off analysis among the criteria discussed previously. Prevailing roadway, traffic, and ambient conditions; driver requirements; and economics are taken into consideration, and the benefits as well as the shortcomings of each technique are rated with regard to those factors. A reliable comparison of various delineation methods and devices must depend on cost-effectiveness on both an initial and a continued basis. The actual selection of the delineation treatment and of the degree of the improvement requires the management decision-making process on a lower level.

Implementation and Performance Evaluation

The selected technique is then put into operation. Once the delineation system becomes exposed to motorists, user acceptability becomes part of the overall performance evaluation of the system. Also, impact on the roadway operation is another input to the performance evaluation. If the system installed proves to be as effective as expected, positive changes should be seen in the number of accidents, the roadway level of service, and the capacity of the delineated roadway. As the driver becomes more secure and confident as a result of the improved delineation, traffic flow over the highway will become steadier.

The performance evaluation not only benefits the road user but also supplies additional input for any future highway delineation studies. This forms a continual process of evaluation and reevaluation of the employed techniques and ensures that the treatments are not kept dormant but undergo continual refinement.

CONCLUSIONS AND RECOMMENDATIONS

The national survey in this study revealed the current practices of state highway departments with respect to roadside delineation concepts. The survey allowed the officials associated with highway safety to express their opinions and to indicate any further studies that they felt should be made. The measure of the relative extent to which the delineation benefit contributes to increased safety is essential to the systematic development of ways and means of obtaining maximum effectiveness of the various types and combinations of roadside delineation.

Based on the results derived from this study and the hope that further research on highway delineation is undertaken, the following recommendations are made:

1. A professional organization should be maintained on a full-time basis to accumulate all of the currently available information on roadside delineation techniques and their effectiveness and to maintain the data on a current basis;
2. Roadside delineation with respect to roadway hazards should be given needed research, especially with respect to delineation techniques and evaluation criteria for effectiveness standard;
3. Further research should be given to areas that require engineering judgment in the specifications of roadside delineation so that the amount of judgment required is reduced to a minimum;
4. Research toward the design of innovative, self-cleaning, nationally accepted delineator devices should be undertaken;
5. A selection program of a roadside delineation technique that is acceptable to all highway departments should be implemented so that uniformity of delineation practices may be more readily obtained and their effectiveness increased; and
6. Further study should be given to a program that all states can readily employ to educate drivers and make them aware of roadside delineation techniques.

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REFERENCES

1. Delineators vs. Edge Stripe: Cost and Effect. Arizona Highway Department, Phoenix, June 1963.
2. Baerwald, J. E., ed. Traffic Engineering Handbook, 3rd Ed. Institute of Traffic Engineers, Washington, D.C., 1965.
3. Blackwell, R. H. Illumination Variables in Visual Tasks of Drivers. Public Roads, Vol. 33, No. 11, 1969.
4. Cantilli, E. J., and Lee, B. Treatment of Roadside Hazards—Decision and Design HRB Spec. Rept. 107, 1970, pp. 101-108.
5. Chaiken, B. Traffic Marking Materials: Summary of Research and Development. Public Roads, Vol. 35, No. 11, 1969.
6. Christie, A. W., Reid, J. A., Rutler, K. S., and Walker, A. E. Edge Markings for Roads With Flush Shoulders. Traffic Engineering and Control, Vol. 4, No. 9, 1963.
7. Dale, J. M. Development of Improved Pavement Marking Materials, Laboratory Phase. NCHRP Rept. 45, 1969.
8. Dart, O. K., Jr. A Study of Roadside Delineator Effectiveness on an Interstate Highway. Highway Research Record 105, 1966, pp. 21-49.
9. David, J. H., and Lett, L. A Study of the Effect of Using Colored Guide Posts on Interstate Highways to Reduce Accidental Damage. Alabama State Highway Department, Montgomery, HPR Rept. 33, 1968.
10. Finch, D. M. Surface-Mounted Lights on Roadways for Guidance. HRB Bull. 266, 1959, pp. 16-26.
11. Fitzpatrick, J. T. Unified Reflective Sign, Pavement, and Delineation Treatments for Night Traffic Guidance. HRB Bull. 255, 1960, pp. 138-145.
12. Hiss, J. G. F., Jr. Pavement Marking Points: Interim Report. Bureau of Physical Research, New York State Department of Transportation, Res. Rept. 67-4, 1969.
13. Musick, J. V. Effect of Pavement Edge Markings on Two-Lane Rural State Highways in Ohio. HRB Bull. 266, 1960, pp. 1-7.
14. Rowan, N. J. Approach-End Treatment of Channelization—Signing and Delineation. Highway Research Record 31, 1963, pp. 57-58.
15. Tamburri, T. N., Hammer, C. J., Jr., Glennon, J. C., and Lew, A. Evaluation of Minor Improvements. Highway Research Record 257, 1968, pp. 34-79.
16. Taragin, A., and Rudy, B. M. Traffic Operations as Related to Highway Illumination and Delineation. HRB Bull. 255, 1960, pp. 1-29.
17. Taylor, J. I., McGee, H. W., Seguin, E. L., and Hostetter, R. S. Roadway Delineation Systems. NCHRP Rept. 130, 1972.
18. Taylor, W. C., and Foody, T. J. Ohio's Curve Delineation Program: An Analysis Traffic Engineering, Vol. 36, No. 9, June 1966.
19. Thomas, I. L., Jr., and Taylor, W. T., Jr. Effect of Edge Striping on Traffic Operations. HRB Bull. 244, 1960, pp. 11-15.
20. Tutt, P. R., and Nixon, J. F. Driver Communication Through Roadway Delineation. Texas Highway Department, Austin, Rept. SS12.1, 1969.
21. Tutt, P. R., and Nixon, J. F. Roadside Design Guidelines. Texas Highway Department, Austin, Rept. SS12.2, 1969.
22. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, 1971.
23. Williston, R. M. Effect of Pavement Edge Markings on Operator Behavior. HRB Bull. 266, 1960, pp 8-27.
24. Yu, J. C. Delineator Effectiveness for Highway Median Visibility. Traffic Engineering and Control, Vol. 11, No. 11, March 1970.
25. Yu, J. C. Driver Performance Related to Median Visibility. HRB Spec. Rept. 107, 1970, p. 180.
26. Yu, J. C. Median Visibility Improvements: Needs, Methods, and Trends. Highway Research Record 366, 1971, pp. 92-101.

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