152 Lighting

TRAFFIC

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 152

WARRANTS FOR HIGHWAY LIGHTING

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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WARRANTS FOR HIGHWAY LIGHTING

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AREAS OF INTEREST:

HIGHWAY SAFETY
TRAFFIC CONTROL AND OPERATIONS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1974

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

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The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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FOREWORD

By Staff
Transportation Research Board

This report will be of particular interest to state and local public officials, whether administrators, traffic engineers, or designers, concerned with decision-making on street and highway lighting installations. The broad investigation reported here has led to the development of warrants useful in determining the justifications for such street and highway lighting installations. The report shows, furthermore, how to apply the warrants and how to make cost-effectiveness evaluations of lighting design alternatives.

Studies of the problems associated with nighttime visibility and highway illumination have been a major part of NCHRP activities since the program's inception. This project, conducted by the Texas Transportation Institute, was directed to the development of warrants for highway lighting, giving consideration particularly to the visual requirements of nighttime drivers. The study was designed to meet a total of seven objectives that are listed in the summary that follows. It has produced a warrant and design procedure that may be used by highway lighting designers to achieve cost-effective solutions appropriate to the visibility problems being addressed. After there has been a reasonable opportunity to test the validity of the recommended procedures in the field, it is anticipated that current design guides can be modified to incorporate the procedures advocated in this report.

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Grateful appreciation also is expressed to the state highway departments, municipalities, and individual experts who so generously contributed their time and talents to the state-of-the-art effort.

Finally, acknowledgment is made to the state highway departments of Texas and Georgia, and to the cities of Dallas, Tex., and Atlanta, Ga., for their excellent cooperation in the conduct of the field studies.

WARRANTS FOR HIGHWAY LIGHTING

SUMMARY

A total design process for roadway lighting has been developed. The process is based on efficiency of night visual communications and traffic facility characteristics.

A cursory review of the literature and the detailed state-of-the-the-art study in roadway lighting research and practice revealed that extremely complex relationships exist within the over-all design process for roadway lighting. Requirements, guidelines, warranting conditions, benefits, priorities, and cost effectiveness are all interrelated to the extent that positive separation is difficult, if not impossible. Therefore, the total design process has been developed around one common framework or concept.

A conceptual framework has been established considering the purpose of lighting itself—to improve the efficiency of night visual communications on traffic facilities through provision of informational needs.

Informational needs have been developed to correspond with the basic levels of driver performance, as follows:

1. Positional level—routine steering and/or speed adjustments necessary to maintain a desired speed and to remain within the lane.
2. Situational level—change in speed, direction of travel, or position on the roadway, required as a result of a change in the geometric, operational, and/or environmental situation.
3. Navigational level—selecting and following a route from the origin to the destination of a trip.

Performance at one level affects performance at the other levels. The driver must attend to positional tasks first, then situational tasks and, finally, navigational tasks.

The diagnostic team approach was used to establish the informational needs. Most needs associated with night driving and lighting were of the situational type. The controlling informational needs were positional, as they determine the time available for situational task performance.

The informational needs developed in the research were classified as to the conditions producing them; i.e., on the basis of geometric, operational, and environmental conditions.

These three classes of conditions were used as parameters for traffic facility classification. The classification was developed to be the manner in which a facility is evaluated for lighting needs and minimum warranting conditions.

The traffic facility classification developed in the research is nothing more than a method of determining visual information needs on a given traffic facility and, thus, justification (warrants) for lighting. Present guides for establishing warrants consist of traffic volumes, locational factors (suburban, urban, etc.), and accident history. The classification developed in the research is a more definite quantification of traffic conditions, geometric conditions, environmental conditions (locational), and accident potential, as well as accident history. The minimum war-

ranting conditions are those for average conditions on a given functional classification.

A positive method for determining the design level of lighting intensity is suggested. It is quantitatively related to the magnitude of warranting conditions and, thus, visual information needs. It is not directly related to any specific visual task problem.

Cost effectiveness was determined as the only method available for economic analysis of roadway lighting. All other methods use monetary evaluations of effectiveness and not all lighting effectiveness can be measured in dollar terms.

This research suggests that benefits or effectiveness be measured in terms of supplying informational needs. As more needs are provided, the effectiveness of lighting increases.

The magnitude of warranting conditions on a given facility, which are dependent on the magnitude of informational needs, serves as the effectiveness measure in priority determination. A priority model was developed based on lighting effectiveness, vehicles or people served, light intensity, size of facility, and annual costs. The priority model favors those facilities with high warranting conditions that can be lighted most economically.

Use of the total design process is illustrated through typical examples taken from field study sites.

It is concluded that the total design process is a usable technique and that AASHTO's *Informational Guide for Roadway Lighting* should be revised to reflect these results. A trial implementation period of approximately one year by responsible agencies has been suggested, with evaluation results to be incorporated into the final revision of the "Informational Guide."

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

THE PROBLEM

The following, taken from the project statement, effectively summarizes the general problem:

> A need exists to establish warrants for fixed roadway lighting on the various classes of roadways in both urban and rural areas; whether the lighting should be continuous in nature or just at specific locations; and guidelines for the design of lighting. Much information on these matters is contained in the literature, but some additional research will be necessary where insufficient data exist. Benefits from fixed-source roadway illumination, including driver performance, comfort, convenience and accident prevention, need to be evaluated.
> Warrants for fixed lighting on specific roadway classes and at local highway situations should include consideration of benefits and costs of lighting (initial and operating) to satisfy the visual requirements of the driver. A method or methods of evaluating costs and benefits of roadway lighting to maximize returns on the investment should be developed for the designer in order to determine the specific design.

Seven research objectives were identified in the project statement, as follows:

1. Review and analyze worldwide research and practice in roadway lighting. Prepare a state-of-the-art summary of the review.
2. Develop requirements for a suitable visual environment to be obtained by fixed roadway lighting for safe and efficient traffic operations. Provide guidelines for the design of fixed roadway lighting to obtain this environment.
3. Evaluate the possible benefits derived when a suitable visual environment is provided by fixed roadway lighting.
4. Determine warrants (the minimum conditions) for where fixed roadway lighting systems should be installed

for continuous lighting and at specific locations, including, but not limited to, interchanges and intersections.

5. Analyze the role of cost-effectiveness and other evaluation techniques in (a) establishing the need for fixed roadway lighting, (b) setting priorities for fixed lighting projects, and (c) evaluating alternative design of lighting.

6. Recommend a method of setting priorities for the installation of fixed lighting.

7. Provide typical example(s) of where lighting is warranted and demonstrate the practical application of objectives one through six.

RESEARCH APPROACH

State of the Art

Literature reviews, questionnaire surveys, and field visits with several states, municipalities, and European countries were used to determine the state of the art. Literature sources of both domestic and foreign origin were reviewed. Questionnaires involving warrants, guidelines, and practices were submitted to the 50 state highway departments, 50 municipalities, and 25 individual experts in the field of lighting. Responses were received from 44 states, 25 municipalities, and 20 experts.

The results of the state-of-the-art review were used to establish much of the direction of the remaining objectives. A state-of-the-art report was submitted as an interim report. A summary of that report, updated to include current research, is included in Chapter Two of this report.

Field Studies

The state-of-the-art review indicated complex relationships existing within the over-all design process for roadway lighting. Requirements, guidelines, warranting conditions, benefits, and priorities are all interrelated to the extent that positive separation is difficult, if not impossible. Consequently, it was necessary for the research approach used in this effort to have a fundamental framework upon which all of the interrelated factors could be developed.

A conceptual framework, based on efficiency of night visual communications and traffic facility classification, was developed for conduct of field studies. The field studies had the purpose of providing subjective information for the development of requirements, guidelines, benefits, warrants, and priorities.

The field studies consisted of subjective evaluations made through diagnostic studies. It was desired that the studies analyze, to the extent possible, the driving task informational needs and the resultant performance of the driver. In addition, some indication was needed as to the adequacy or inadequacy of the visual environment in providing necessary visual inputs. Therefore, the field studies attempted to investigate the cause or nature of conditions, situations, and problems as related to the driving task. Finally, it was desirable to involve as many people as possible in the development of the requirements of the visual environment. Thus, a team representing both professionals and lay people participated. A summary description of the field study approach would be: "A team of individuals representing professionals and lay drivers diagnosing the cause or nature of conditions, situations, or problems relating to the driving task at night."

The results of the field studies were used to develop a procedure for the analysis of given traffic facilities to determine the need for lighting, warranting conditions, resulting benefits, design guidelines, and priorities for installation of lighting systems.

Details of the field study techniques are reported in later sections.

CHAPTER TWO

FINDINGS

STATE-OF-THE-ART SUMMARY

Man's progress in the development of lighting has evolved from primitive uses of fire to modern-day illumination. The basic motivation of people desiring artificial lighting at night has remained unchanged over the years. Application of artificial lighting to streets and highways has also resulted from the same basic motivation, but emphasis on the application or objectives has changed. In order of chronological development, the objectives of street and highway lighting are as follows:

1. Crime reduction.
2. Civic improvement.
3. Traffic safety.

The history of street lighting dates back to the Fifteenth Century, when citizens of London and Paris began to carry their own lanterns at night. The provision of street lighting by the government was begun in Paris in 1866, when lanterns were hung on ropes stretched across the streets. This practice also became popular in England and throughout the Continent. Changes in lamp innovations for street and roadway lighting took place over the years. Today, a number of light sources with efficiencies of from 25 to 175 lumens per watt are being used successfully in street lighting applications.

All of the earlier artificial lights for street lighting were normally mounted at heights of 10 to 20 ft. The power of the electric arc lamp gave rise to a number of early installations involving extremely high poles or towers. In 1881 the City of Cleveland, Ohio, installed four 250-ft steel masts. But by 1883 it had been decided that higher mounting heights produced inefficient light, so the one tower that remained was reduced to a height of 100 ft. Many other cities installed towers as high as 90 to 165 ft, although none are now in existence except those in Austin, Tex.

Modern practice has seen mounting heights grow from 20 to 40, 50, or 60 ft. Many states now employ the high-intensity lighting sources and, consequently, are returning to extreme mounting heights of 60 to 200 ft for special lighting situations, such as complex interchanges.

The development of modern-day street lighting has been accompanied by significant events in other related areas, such as visual research, benefits of lighting, and guidelines for design and cost-effectiveness. These developments are presented in the following discussions.

Driver Performance and Visual Information Needs

One apparent problem involving roadway lighting is the definition of visibility. Most laboratory experiments in visibility have been psychophysical in nature. That is, the variables are physical (brightness, color, angle or retinal position, angular subtense or retinal size, contrast, duration, and period), and the response is usually some subjective judgment. In human factors and in physiology, other variables such as vibration and emotional set are used, but there is a tendency toward less sophistication in specifying the physical parameters. On the roadway, the physical variables are space, time, light distribution, and contrast, in addition to numerous human variables. The primary aim is to translate psychophysical results from the laboratory into physical design criteria for the roadway in a manner that will enhance proper human performance under night-driving conditions.

Of the several methods for determining visibility, the first is contrast. To a great extent, the recognition of objects is based on a discrimination of brightness differences (*1*). For night conditions an obstacle may appear as a dark area against a bright background (silhouette) or it may appear as a bright area against a dark background (reverse silhouette).

Contrast is a photometrically measurable and calculable luminance difference of two areas, and the ability to distinguish luminance differences is defined as contrast sensitivity. The barely recognizable luminance difference of two areas is the differential threshold, which changes during adaptation and serves to measure the progress of adaptation.

The visibility of an object can fluctuate greatly with position, headlights, and other sources of illumination. Under certain illumination conditions the target or object of concern can be made to disappear entirely unless the target has zero reflectance, a condition not found in nature. Another important fact is that visibility is a function of contrast at the corner of an object. It is possible for a relatively small portion of a large object to be far more visible than the rest of the object if the contrast difference along its border is very great (*2*).

Contrast sensitivity provides for the detection of objects, whereas the identification of an object is accomplished by visual acuity, which is the ability of the eye to resolve small detail. In the driving task, there are two types of visual acuity in operation.

Static visual acuity occurs when both the observer and the object are stationary. Clinical measurement of visual acuity is based on a size scale of black letters or numbers on a well-illuminated white background. If a person, from a standard distance, resolves a letter subtending 5 min of arc, of which each interspace or each width of letter bar subtends 1 min of arc, this person has a visual acuity of 1.0. If he can resolve only letters, the critical details of which subtend 8 min of arc, he has one-eighth visual acuity. Thus, visual acuity is expressed by the reciprocal of the minutes of subtense of resolvable critical details. It is also expressed as a ratio of distances. A person has 20/20 vision when he can read letters that subtend 5 min of arc at a distance of 20 ft. Vehicle operators show a prevalence of 20/20 visual acuity (*3*).

With increasing level of illumination, visual acuity increases up to a background brightness of about 10 mL and then remains relatively constant. The eyes of older persons require more illumination for a visual acuity task than do those of young people (*1*).

When there is a relative motion between the observer and the object, such as occurs during driving, the resolving ability of the eye is termed dynamic visual acuity (*1*). It is usually measured by presenting a moving target, variable in size, and determining the size that can be resolved. Dynamic visual acuity is worse than static visual acuity because eye movements are not generally capable of holding a steady image of the target on the retina. The image is blurred; therefore, its contrast decreases. The conditions favorable for dynamic visual acuity are slow movement, long tracking time, and good illumination (*1*).

Those factors which modify vision have been investigated extensively, and two primary modifiers of major concern have been identified—disability or physiological glare and discomfort or psychological glare. Disability glare reduces contrast sensitivity, whereas discomfort glare produces ocular discomfort.

Advancements in the knowledge of the effects of glare on driver performance, driver comfort, and visual performance have made it possible to develop empirical techniques of glare evaluation (*4, 5, 6, 7, 8*). Use of these techniques allows engineers to objectively determine the amount of glare present in a given lighting system and to estimate the magnitude of its effects on the driver. Most methods for appraising glare permit rapid evaluation and may serve as a basis for practical use. It can be stated, however, that they do not include any recommendations as to what extent glare in street lighting should be restricted. Nearly all street lighting codes, both national and international, deal with glare control in a generally vague manner. This important factor needs much greater attention so that good street lighting can be designed which will benefit safety and night driving comfort.

Despite the tremendous literature on driver vision, one question remains paramount—what elements of the visual environment serve as input for proper vehicle control and operation? A number of attempts have been made to characterize driving performance in terms of the ways and means in which drivers extract information from the environment and translate this information into vehicular control action. The purpose of information, whether through visual or other sense modalities, is to reduce uncertainty. In order to make rational decisions, the driver must reduce his uncertainty.

Driver information needs are a direct function of what the driver does in performance of the driving task. Thus, to define the requirements of a suitable night-driving visual environment, it becomes necessary to have a firm understanding of the driving task and the associated visual information needs.

There are three basic levels in the driving task. During normal driving, all three are performed simultaneously. As the complexity of the driving task increases, there is a tendency to ignore the higher-order levels (level 3 then level 2) in order to concentrate on the lower-order level.

The three basic levels are defined operationally, as follows (*9*):

1. *Positional level*—Routine steering and/or speed adjustments necessary to maintain a desired speed and to remain within the lane. These are two major subtasks at the positional level—steering control and speed control, with elements of each involved in all major levels of the driving task.

2. *Situational level*—Change in speed, direction of travel, or position on the roadway, required as a result of a change in the geometric, operational, and/or environmental situation. Information needs at this level involve information relative to all aspects of the highway system, such as other cars, road geometrics, obstacles, weather conditions. Performance at this level is a function of the driver's perception of a situation and his ability to respond in an appropriate manner.

3. *Navigational level*—Selecting and following a route from the origin to the destination of a trip. The navigational level takes into account the way in which a driver plans a trip and executes his trip plan in transit. This level consists of two basic categories. These include trip preparation and planning, which is usually a pretrip activity, and direction-finding, which occurs while in transit.

From this brief review of driver tasks and informational needs, it is evident that drivers need certain levels of information to perform the driving task adequately. From practice, this information is normally provided by the vehicle headlights, and fixed lighting is used to supplement the vehicle headlights where they do not adequately provide visual information. Thus, the informational requirements are the primary determinants in the establishment of positive guidelines or warranting conditions for fixed lighting.

Fixed Lighting Warrants

The literature is abundant with technology of fixed lighting, benefits of these installations, and visual environments; however, it is almost totally void of any research dealing with warranting conditions. The lack of adequate research on fixed lighting warrants is evidenced in the rather arbitrary nature of most published reports. The warrants currently in use are based primarily on engineering experience and judgment with little, if any, factual data base. Review of the roadway lighting warrants currently in use (*10, 11, 12*) reveals that three broad policies are being employed in establishing roadway illumination warrants:

Policy I—Minimize sites warranting lighting. Fixed illumination is desirable on all classes of roadways but, due to the limitation of available funds, only a few sites should be warranted in order to have a firm basis for declining to light a section of roadway when requested to do so. Thus, the warranting conditions should be set very high.

Policy II—Maximize sites warranting lighting. Fixed illumination is desirable on all classes of roadways, and available funds will be provided for illumination on relatively few. To encourage the allocation of local funds to pay the installation, maintenance, and energy costs associated with fixed illumination, the warrants should be very liberal so that all roadways with a substantial volume of traffic warrant lighting.

Policy III—Only where economically justified. Fixed illumination should be provided only at roadway points that are geometrically complex, because fixed illumination cannot be economically justified for most sections of roadway.

It is also apparent that most of the warrants currently in use are very arbitrary and are frequently without substantial foundation. This is not to say that the warrants were not established by logical engineering evaluation of the problem. Rather, it appears that the warrants have been established from a broad philosophic position and logical deduction. Often the process of arbitration results in the final set of warrants which includes several philosophies, rather than just one. This suggests the possibility that several different sets of basic warrants may be desirable, each developed to be consistent with a particular design strategy. Such a system of warrants would be somewhat cumbersome to administer, especially on a national scope.

Finally, all of the sets of warrants reviewed could justify lighting for any roadway carrying a substantial volume of traffic and, therefore, the functional value of the warrant concept may well have been lost. The warrants appear to be used more for establishing the actual governmental agencies that will participate in the financing of the lighting system, rather than for establishing the minimum conditions for which illumination can be expected to be effective.

As part of the state-of-the-art study, questionnaires were constructed to provide information on warrants, guidelines, and practices of roadway lighting. To identify any possible weakness in the AASHTO warrants, the attitudes of state highway engineers, public works departments, and other experts in the field of roadway lighting toward the AASHTO guidelines were obtained from the questionnaire. The questionnaire was composed of 33 statements concerning the various guidelines from the AASHTO manual, *An Informational Guide for Roadway Lighting*. These statements covered warranting conditions and design values for the following areas:

1. Freeways.
2. Highways other than freeways.
3. Tunnels and underpasses.
4. Interchanges and intersections of freeways and other highways.

Based on an analysis of the questionnaire, several conclusions may be drawn concerning the sufficiency of the AASHTO guidelines. The most important conclusion was that, of the engineers surveyed, only a few appeared to support wholeheartedly the guidelines in their present form. Although there is general agreement with the guidelines, the responses of the participants indicate several areas of necessary improvement. There is a definite need for the development of relevant, objective design criteria for the installation of lighting systems on freeways, interchanges and intersections, and streets and highways other than freeways. Furthermore, warranting criteria of an empirical nature should be determined and established on the basis of objectively obtainable information. This would greatly facilitate the setting of lighting job priorities and lighting system design. In addition, quantitative guidelines are required and should be developed for bridges and other specialized structures.

Fixed Lighting Guidelines and Practices

The parameters of illumination guidelines as determined in the state-of-the-art study are (*10, 11, 13*):

1. System requirements—objectives to be accomplished by fixed roadway lighting. This category was considered the most important, as its subtopics are presently receiving the most attention in the literature.
2. Design criteria—Realization of the system requirements in terms of photometric quantities.
3. Design procedure and calculations—Realization of the design criteria.
4. Sources of illumination—Various types of lamps employed in roadway lighting and the advantages or disadvantages of each.
5. Hardware—Types of luminaires, poles, and bases used for roadway lighting, in terms of utility and safety.
6. Electric power considerations and maintenance.

System Requirements

To a large extent, one factor is uniquely distinguished and isolated by virtue of cost. That is, the roadway lighting system is confined to low levels of light in such a direction as to affect vision by silhouette. This has been the most fundamental and important guideline. Unquestionably, the provision of fixed lighting will make objects more visible. Ultimately, however, the visibility that a system produces depends directly on pavement reflectance, which is normally beyond the control of the roadway illumination designer.

It should be noted that current design practice is based on maximizing the light on the roadway and minimizing the light off the roadway. Indeed, this is the most prudent use of available light, and is perhaps a desirable characteristic for lighting systems in residential areas; however, the benefits to be gained from light on the periphery of other roadways must not be overlooked. These include orientation at critical decision points, as in the case of high-mast lighting; a panoramic view more closely resembling daytime conditions; and the provision of better uniformity and less glare.

Design Criteria

As previously stated, the purpose of the roadway illumination system is to provide silhouette vision by making the horizontal component of illumination exceed the vertical component. The main performance criterion has become the physical measurement of horizontal footcandles and, quite naturally, specification thereof is an important criterion for design. Some objection to the use of horizontal footcandles has been reported, the criticism being that horizontal illumination does not produce visibility. It is stated that visibility at low light levels is due to brightness contrast and, therefore, brightness measurements would be a better performance criterion. Due to a widely proclaimed lack of reflectance data for various materials, brightness performance would be unwieldy for design. Present practice involves specification of an average level of horizontal footcandles, with mounting height and luminaire support spacing calculated to yield this level of illumination. Thus, brightness is not specified as a design or performance criterion.

Design Procedure and Calculations

Two distinct methods are used by state highway departments to calculate luminaire support spacing. The first requires physical measurement of the horizontal footcandle distribution at a particular mounting height for a particular lamp and luminaire, from which isofootcandle contours are plotted. At least two clear-plastic overlaps are prepared from the contour plot, from which the contours corresponding to one-half the minimum level to be allowed are superimposed along a plan of the roadway. As the values associated with each contour are added linearly, a graphic presentation of the horizontal illumination along the roadway is easily and readily established.

The other method (*11, 13*) shows that the spacing, S, may be computed by

$$S = (L_H C_U F_T F_M)/(W_R f_{AM}) \tag{1}$$

in which

L_H = horizontal lumens;
C_U = coefficient of utilization;
F_T = temperature factor;
F_M = maintenance factor (dirt);
W_R = roadway width; and
f_{AM} = average maintained horizontal footcandles.

It has been mentioned by Ketvirtis (*11*) and others that the spacing distance calculated by Eq. 1 may result in illumination levels quite different from the level that was intended. The formula does provide an initial approach to the spacing problem, once the mounting height and the average horizontal illumination have been determined. Its use was never intended to replace experience and professional judgment.

For years luminaire mounting heights of approximately 30 ft and lamp outputs on the order of 15,000 lumens served as the chief means of implementing illumination theory and practice. Strictly speaking, the only variable at the disposal of the roadway lighting designer was the spacing between the luminaire supports. As designers began seeking lower uniformity ratios, lamps of greater luminous output became available, and increased mounting height was deemed desirable. Today many lighting authorities specify 50-ft mounting heights with sources of 50,000 to 90,000 lumens. It is apparent that higher mounting heights and sources of greater intensity more closely achieve system requirements. For this reason, higher mounting heights and multiple light sources for interchanges, multi-level expressways, and other difficult roadway geometrics are much in evidence.

Sources of Illumination

Not taking power sources into consideration, the types of illumination sources preferred now are mercury vapor, color-improved mercury vapor, metal halide, and high-pressure sodium vapor. Reactions to each type include some mention of the color produced and, in the case of sodium, opinions ranging from tolerant to violent. Public reaction has been the most favorable toward the fluorescent variety. It is well known that sodium vapor lamps produce approximately twice the lumens per watt as mercury vapor.

Whatever the reasons for a particular preference, it has been experimentally verified that the lamp's color has little, if any, influence on visibility. This means that selection of a lamp for a particular color will not visually benefit the driver. It has, however, been mentioned that adaptation time is possibly less for sodium vapor lighting.

By far, mercury vapor lamps have been the most preferred choice. Reasons for this include compact size, long life, and good lumen/watt efficiency. Widespread experience with these lamps has resulted in standardization, interchangeability, and quality control. For other sources to compete with mercury vapor, they must do so in terms of the foregoing reasons, without the sales/user experience, and may or may not have the same degree of standardization, interchangeability, or quality control. High-pressure sodium and metal halide lamps offer higher efficiency but considerably shorter lifetimes.

Hardware

A consideration that certainly deserves attention is the hardware used in lighting designs, especially for the supports and the luminaires. The steel pole-cast aluminum "transformer base" combination is generally the most satisfactory in terms of breakaway characteristics and utility; however, such a flat statement regarding luminaires cannot be made. Types from which to choose include open, sealed (sometimes semi-sealed) with or without filter, and integral ballast; all have varying degrees of cut-off. Refractor/reflector design is another variable and *must* be considered in terms of light distribution.

Electric Power Considerations and Maintenance

Many lighting installations require enough electrical power to justify special distribution equipment and coordination with an electric power utility company. Usually the operating line voltage is available in multiples of 120, the upper limit being determined by the breakdown voltage of the insulation used in each component of the system.

Lamps used for roadway lighting are of the gas-discharge type and require current limiting while burning. This is accomplished by placing a coil of enough inductance, called a ballast, in series with the lamp. It is usual practice to incorporate an autotransformer with the ballast, so that voltage changes (step up or step down) are facilitated. To minimize line losses, the operating voltage must be as high as possible (that is, 480 v).

Reduction of light due to dirt and lumen depreciation of the lamp is too gradual to be observed daily. Thus, periodic cleaning and relamping are important maintenance requirements. It is reported that these maintenance intervals range from six months to four years, with the work usually being performed by an electric utility company. An increasing number of luminaires use polished aluminum as the reflector; this is easily tarnished or damaged. Mentioned recently in a trade journal was a cleaning solution made especially for polished aluminum. This not only makes use of these reflectors more feasible, but also provides for adequate maintenance.

Generally, the benefits of maintenance parallel the benefits of illumination in the first place, and the most effective cleaning schedule is based on an interval allowing a 20 percent reduction of light due to dirt. Lamp replacement should follow the same schedule. This amounts to approximately 16,000 hr of service at rated conditions for mercury vapor lamps, making the four-year interval a tolerable period of time.

Benefits of Fixed Lighting

The benefits accruable to fixed roadway lighting may be classified according to effect into the following groups:

1. Driver comfort.
2. Driver safety.
3. Traffic operations.
4. Socioeconomic factors.

In each of these groups, fixed lighting has been shown to have a beneficial effect. For example, fixed lighting often results in a decrease of 45 percent or more in the rate of nighttime accidents (*14*). Accompanying this decrease is a proportional reduction in the cost of injuries, property damage, and automobile repairs. Furthermore, there is some evidence that the nighttime capacity of freeways and highways may be increased when illumination is provided (*15*). This could be significant in areas where the peak period occurs during hours of darkness.

The psychological state of the driver, although difficult to quantify, has been shown to respond favorably to increased levels of roadway illumination. Several studies have provided evidence of an empirical nature that adequately substantiates this claim (*16, 17*).

There are a number of socioeconomic benefits associated with fixed illumination and these revolve around two basic precepts: the attraction of customers to shopping centers after dark, and the prevention of crime and pedestrian deaths during hours of darkness. The beneficial effects of illumination in these areas have also been well documented (*18, 19, 20, 21, 22, 23*).

The economic benefits of lighting are many and manifest themselves in such ways as reduced accident cost, reduced damage to roadway structures, and increased business in downtown areas. Many downtown areas, almost totally deserted after dark, have increased their aesthetic appeal and amount of business after the addition of improved lighting. Architects and city planners have found light to be a major source of economic stimulation and beautification for their downtown areas. In fact, many large cities across the country are once again opening their parks and recreation areas after dark because of the effects lighting has on the crime rate, business, and personal security. Police forces across the entire United States have praised and actively supported improved lighting to make their own jobs easier and more manageable.

Over the past 15 years, many aspects of the interaction between the driver and fixed roadway illumination have been studied, and many questions have been answered. It is now known that, almost without exception, improved lighting results in fewer deaths on the highways, reductions in the cost of those accidents that do occur, increased economic stimulation of business, increased personal safety on the streets, and drastic reductions in crime. However, to date little is known as to the exact nature of the effects of lighting on driving performance. It is evident that illumination can result in better vehicle positioning, increased system capacity, and a more relaxed and stable emotional state on the part of the driver. However, how do these and other factors act to reduce the probability of an accident? Is increased visibility the only factor of any importance? These and many other questions concerning benefits are currently being studied by researchers throughout the world. Studies are being conducted involving the effects of glare from roadway illumination systems on vision and driving behavior, the effect of lighting on car following and lag acceptance, etc. Criteria are being developed for the illumination of rural roadways, intersections, bridges, and other types of highway structures. Already several states are going to higher mounting heights to reduce glare, improve transition, and increase the illumination of the surrounding roadway environment. Studies are being conducted to discover the effect of illumination on depth perception, distance, speed, and time estimates, as well as many other psychological parameters of the driver and his environment. In any event, the future seems bright, at least so far as benefits and candlepower of roadway lighting are concerned.

The one negative comment that can be leveled at research concerned with illumination is that little is known about the reasons why illumination affects the previously mentioned benefits. Several important questions remain unanswered. Why does illumination of a traffic facility result in a decrease in the number of accidents? Why do drivers feel more secure under illuminated conditions? Why are street crimes reduced under illuminated conditions? These and many other questions of this nature have not been answered or even thoroughly investigated in current times. Until these relationships are thoroughly established, it will be impossible to specify the nature of the interaction of illumination with any type of human performance variable.

Cost-Effectiveness and Other Evaluation Techniques

Several methods of evaluating lighting alternatives have been considered in the past. Use of all of these methods except one—the cost-effectiveness method—necessitates estimation of the benefits of lighting in dollar terms.

The appropriateness of using methods that entail estimation of benefits in dollar terms depends on whether these benefits can in fact be estimated in such terms. The principal benefits that usually are considered in comparison of lighting alternatives are changes in travel times, vehicle operating costs, numbers of accidents, comfort or discomfort, and crime. There exist fairly good estimates of the unit dollar values for time and operating costs, and also for the direct cost of accidents. There currently exists, however, no way of estimating in dollar terms the increase in driver comfort due to lighting. This seriously limits the use of methods that entail the estimation of the benefits of lighting in dollar terms.

On the other hand, the cost-effectiveness method of analysis, use of which does not necessitate estimation of benefits in dollar terms, can be used only for comparing alternatives that have the same level of effectiveness or cost. Therefore, the cost-effectiveness method gives only an indirect indication of priorities for lighting.

In summary, a method of analysis that entails estimation of benefits in dollar terms, such as the benefit-cost method or the rate-of-return method, can be used for comparing alternatives and for determining priorities, but it must be recognized that all of the benefits cannot be estimated in dollar terms and, therefore, the use of such a method is at least partially inaccurate. What are probably the most important benefits of lighting, reductions in driver discomfort, and increases in communications, cannot be estimated in dollar terms. Also, the cost of accidents can be estimated only partially in dollar terms.

European Practices and Technology

A discussion limited to those roadway lighting techniques and practices within the boundaries of the United States would not in itself provide a complete state of the art. Total consideration of the roadway lighting field must also reflect international considerations. Therefore, the advisory panel recommended that, as part of the project, a tour of seven European countries be conducted for the purpose of observing the latest practices and technology in roadway lighting.

It was found that, in general, a great amount of enthusiasm is exhibited by those associated with the field of roadway lighting in the various European countries. This was characteristic of all agencies involved, including the manufacturing, governmental, municipal, educational, and research representatives. Also, the qualifications of people associated with public lighting are quite high. It does appear, however, that the lighting profession in Europe is more scientifically oriented than is the lighting profession in the United States.

Warrants

Few European countries have clearly defined warrants for roadway lighting. It is generally an established practice that all urban streets are to be lighted, and the quality of the lighting system is to be commensurate with the amount and quality of traffic flow on the facility. The Netherlands has a basic warrant for lighting motorways; simply stated, all motorways with three or more lanes in each direction shall be lighted. On the other hand, Great Britain uses a rigorous economic analysis of accident costs as related to the cost of the lighting system to determine warranting conditions for motorways and principal roadways. The economic analysis is based on an assumed 30% reduction in night accidents. Belgium uses strictly an average daily traffic of 10,000 vehicles as a warranting condition for main roads.

Guidelines for Design

Most of the continental European countries support the luminance concept of design, as recommended by the Commission International de l'Eclairage; however, Great Britain believes that such a design procedure is far more scientific than is necessary. They believe that adoption of these recommendations would virtually place the design of lighting in the hands of qualified consultants and the technical staffs of lighting manufacturers. Great Britain also believes that pavement reflectance and glare are important considerations and should definitely be integrated with a standard code of practice that can be used, without difficulty, by the typical lighting engineer.

Glare Considerations

As a whole, Europeans are extremely sensitive to glare. Practically all street-lighting equipment is of the complete cut-off type, and glare is a big factor in their design procedures. There is a difference of opinion concerning glare among the experts in the field. Professor de Boer, of The Netherlands, is of the opinion that when discomfort glare has been taken care of, disability glare is no longer a significant problem. On the other hand, Dr. Adrian, of Karlsruhe University, is of the opinion that disability glare is the most important consideration.

Light Sources

Virtually all types of common light sources were found in various applications throughout all countries visited. There was a general tendency toward use of sodium sources in countries characteristically known for cold and foggy climates, whereas the cool, white sources were more common in the warm countries such as France and Italy. Low-pressure sodium was observed as the most popular light source because of its relative efficiency (up to 180 lumens per watt). High-pressure sodium is making a tremendous gain in popularity because it provides a relatively high efficiency with acceptable color rendition. Mercury lighting remains fairly popular. Xenon sources have been used for special high-mast lighting applications in the past, but no new installations are anticipated. As to the future, it appears that high-pressure sodium is the most promising.

High-Mast Lighting

High-mast lighting has just been installed in a number of European countries, but is receiving the greatest enthusiasm in Great Britain. High-pressure sodium is the most commonly used light source for new high-mast lighting installations. The mounting height is normally about 100 ft, and light sources are 400- and 600-w units.

New Lighting Concepts

Catenary lighting is the newest lighting concept in Europe. It gets its name from the method of suspending lighting units from a catenary wire between successive masts. The lighting units are spaced at 1 to 1.5 mounting heights; the masts are spaced at 4 to 6 mounting heights. The Netherlands has installed a substantial amount of catenary lighting, using low-pressure sodium light sources mounted at 10-m height and 12-m spacing. A dual catenary system has been used in the outer separations of a large cloverleaf interchange with collector-distributor roads. Two sections of catenary lighting have been installed in Germany on an experimental basis. One employs mercury light sources, whereas the other uses fluorescent sources. Great Britain is in the process of installing its first system of catenary lighting (near London).

Belgium is considering 18-m mounting heights and 54-m spacings of high-pressure sodium for continuous lighting. Switzerland is using 20-m mounting heights and 80-m spacings of high-pressure sodium for freeway lighting. The trend is definitely toward higher mounting heights for continuous roadway lighting.

CONCEPTUAL FRAMEWORK

It has been stated that the function of lighting is to improve the efficiency of night visual communications. The conceptual framework upon which the project objectives were developed was based on this function using visual information needs for night task performance as the basic measure of effectiveness.

The purpose of information, whether through visual or other sense modalities, is to reduce uncertainty. In order to make efficient and rational decisions, the driver must reduce his uncertainty.

Driver visual information needs are a direct function of what the driver does in performance of the driving task. Thus, to arrive at the requirements of a suitable visual environment, it becomes necessary to have a basic understanding of the driving task.

Driving Task

There are three basic levels in the driving task: (1) positional level, (2) situational level, and (3) navigational level. During normal driving all three are performed simultaneously. As the complexity of the driving task increases there is a tendency to ignore the higher-order levels (level 3 then level 2) in order to concentrate on the lower-order level.

The three basic levels are defined operationally as follows:

Positional level—routine steering and/or speed adjustments necessary to maintain a desired speed and to remain within the lane.

Situational level—change in speed, direction of travel, or position on the roadway, required as a result of a change in the geometric, operational, and/or environmental situation.

Navigational level—selecting and following a route from the origin to the destination of a trip.

These levels can be ordered into a hierarchy that describes the organizational content of the driving task (*9*) according to time scale and the level of cognitive activity. The levels differ in the time scale relevant to their performance and the level of cognition required by the driver. Analysis of the ordering reveals that performance at one level affects performance at the other levels.

An important characteristic of the driving task description is that it describes which level the driver will and/or should attend to as a function of the demands of the situation. When performance demands are minimal for levels in the ordering, these are performed with little conscious attention. In these cases, the driver's attention may be directed toward levels higher in the hierarchy. However, when high performance demands occur at any level, the driver should not attend to any level higher in the hierarchy, but still must attend to those lower in the hierarchy. Thus, the hierarchy describes the manner in which the driver behaves when he becomes overloaded by demands at any level of performance. In an overloaded situation, the driver sheds (work load shedding) all driving task levels higher, but not those lower.

The description permits establishing a priority (primacy) of task levels and their associated information needs; information needs lower in the hierarchy have priority over needs higher in the hierarchy. This priority results from the load-shedding described previously.

Another important factor in describing the driving task is expectancy. The driver has an expectation of the vehicle response to his steering movements, learned by experience. Similarly, he has expectations concerning the curvature of the roadway, the behavior of other vehicles, and the signs he will find to direct him on his route. The expectancies, which apply to short distances ahead for the positional level and long distances ahead for the navigational level, play an important part in the integration of the driving task. When such expectancies are not fulfilled for one of the levels, performance of that level, and perhaps the lower levels, may be seriously disrupted, perhaps resulting in hazardous driving.

To summarize, there are three levels involved in the driving task. These levels are conceptually and empirically sound (*9*).

Visual Information Needs

Visual information needs associated with the driving task can be organized in accordance with the levels previously described. Although previous research has not made it possible to provide a complete inventory of visual information needs that take into account all possible trips and situations, it is possible to derive a list representative of the types of needs associated with typical levels. These needs, discussed in the context of the three levels of the driving task, are presented in the following.

Positional Information Needs

There are essentially two major positional subtasks at the positional level—steering control and speed control—with elements of each involved in all major levels of the driving task.

The major information needs associated with steering control involve vehicle response characteristics and vehicle location information, and all changes thereof. The following information needs, as determined through driver-vehicle task analysis (*9*), are those necessary for satisfying the requirements for steering control and speed control:

A. Steering control:
   1. Lateral position information with respect to the road, to apply minute steering corrections, thus maintaining a desired position.
   2. Spatial orientation with respect to the roadway immediately ahead to provide for location and relative lateral movement with respect to the roadway.
   3. Visual feedback of changes in position and orientation with respect to the road.
   4. Information on changes in vehicle response when high demands are placed on the steering task (non-visual information).
   5. Tactile and kinesthetic perception of accelerator, brake pedal, and vehicle response.

B. Speed control:
   1. Visibility of the roadway at a sufficient distance to bring the vehicle there at a safe speed.
   2. Visibility to reveal conditions on the roadway not consistent with the driver's expectancy.
   3. Integration of speed control with the steering control requirements.

Several research efforts provide details of those elements of the night-driving visual environment that satisfy the visual information needs listed for steering and speed control. These details are as follows:

A. Steering control:
   1. Lateral position information with respect to the road:
      (a) Lane marker on the lined road.
      (b) Edge markers (edgelines) on the road.
      (c) Curb delineation.

(d) Presentation of items a, b, and c at a minimum distance of 100 ft.

2. Spatial orientation with respect to the roadway immediately ahead:
   (a) Position of road edges.
   (b) Position of lane division.
   (c) Perception of roadside features.
   (d) Presentation of items a, b, and c at a minimum distance of 100 ft.
3. Visual feedback of changes in position and orientation with respect to the road:
   (a) Position of road edges.
   (b) Position of lane divisions.
   (c) Perception of roadside features.
   (d) Presentation of items a, b, and c at a minimum distance of 100 ft.

B. Speed control:
1. Visibility of the roadway at a sufficient distance to bring the vehicle there at a safe speed:
   (a) Perception of movement relative to the visual field.
   (b) Perception of roadway and environmental cues.
   (c) A priori information.
   (d) Perception of speed limit signs.
   (e) Perception of inclement weather conditions.
2. Visibility to reveal conditions of the roadway not consistent with the driver's expectancy:
   (a) Extremities of the roadway.
   (b) Roadway boundaries.
   (c) Road geometry as far ahead as possible, and desirable at least 1,000 ft ahead.
3. Integration of speed control with the steering control requirements:
   (a) No specific visual information needed.

Situational Information Needs

Situational information involves that information which indicates a need for a change in speed, direction of travel, or position on the roadway, required as a result of a change in the geometric, traffic, and/or environmental situation. Whereas the positional tasks and associated information needs are limited, the situational subtasks and information needs are as varied as the number and types of road and traffic situations encountered in traffic. Information needs at this level involve information relative to all aspects of the highway system, such as other cars, road geometrics, obstacles, weather conditions.

Performance at this level is a function of the driver's perception of a situation and his ability to respond in an appropriate manner. Therefore, the driver must have a store of a priori knowledge on which to base his control actions, as well as an understanding of what the situation demands.

Subtasks at the situational level of performance can be broken into three broad categories—car following, overtaking and passing, and other situational subtasks (*9*). The information needs that follow are presented as related to these three categories:

A. Car following—In car following the driver is constantly modifying his car's speed to maintain a safe gap between his car and the vehicle he is following. Thus, in this situation, he is time-sharing tracking with speed control activity. The minimal information needs are:
1. Lead car speed and changes in its speed.
2. Following car speed and the relative distance between the driver's vehicle and the lead vehicle.
3. Environmental information to maintain an appreciation of the dynamic situation.

B. Overtaking and passing—A second situational subtask that commonly occurs is passing, which involves, in addition to speed control, modifications in the basic tracking activity. In passing, the driver is required to know control information so as to maneuver his vehicle most safely. Minimal information needs are:
1. Control information on how fast the lead car is traveling and the acceptable gap.
2. Environmental information to maintain an appreciation of the dynamic situation.
3. Information to provide for judgment, prediction, estimation, and feedback to maintain an area of safe travel relative to the vehicle and other elements of the highway system.

C. Other situational subtasks—Among the situational subtasks that may occur are avoidance of pedestrians or other objects and response to traffic signals, advisory signs, and other formal and informal information carriers. In all cases, the important point, in terms of information needs, is that the driver must receive information so that be is aware of the occurrence of a situation and he knows what the situation is. Minimal information needs are:
1. Information to maintain a complete appreciation of all events that could possibly offset safe travel.
2. Visual information of the relationship of the driver's vehicle to the road, other vehicles, and the environment.
3. Information from the environment and a priori knowledge that will provide for appropriate steering and speed control responses, and feedback information that will indicate the adequacy of the response.

Navigational Information Needs

To fully describe informational needs in driving, the third level of performance, the navigational level, must be considered. This level takes into account the way in which the driver plans a trip and executes his trip plan in transit. The navigational level consists of two basic categories—trip preparation and planning, which is usually a pretrip activity, and direction finding, which occurs while in transit.

A. Trip preparation and planning—Drivers use various means to formulate trip plans, depending on experience, pretrip sources, and the nature of the trip. The means can be as formal as having the trip planned by a touring service, or as simple as using a route used previously. However minimal the preparation, it is unlikely that a driver will attempt to get to some destination completely unprepared.

B. Direction finding—During this phase, the driver on the road must find his destination in the highway system in accordance with his trip plan and the directional information received in transit. He must thus share navigational subtasks with subtasks at the other driving levels. The information needs associated with direction finding are:
   1. In-trip visual information regarding guide and service signs, and other formal information sources.
   2. In-trip visual information regarding landmarks, the environment and other informal information sources.

The practical utility of the driving task description and associated information needs is the development of a driver informational needs inventory descriptive of the night-driving visual environment. This inventory should conform to the basic levels discussed previously and should be structured around the concepts of primacy and expectancy. In addition, the descriptive informational needs should be structured about geometric, operational, and environmental conditions found on the street and highway system. Tables 1, 2, and 3 present the informational needs inventory as related to the levels of driving performance and to the concepts of primacy and expectancy. In later sections these inventories are validated and/or modified as indicated by the field studies and categorized about the geometric, operational, and environmental conditions encountered.

Traffic Facility Classification

This phase of the research is devoted to a conceptual classification of the street and highway system on the basis of conditions and situations that characterize traffic facilities.

TABLE 1

DRIVER INFORMATION NEEDS INVENTORY AS RELATED TO POSITIONAL PERFORMANCE LEVEL [a]

INFORMATION NEED	DEFINITION	VISUAL CONTRIBUTION
Vehicle handling characteristics	Information relating to vehicle handling (accel., braking, steering, ride, cornering, etc.)	Perception of environment.
Lateral location	Information providing the driver with data as to where his car is in relation to fixed boundaries of a road.	Perception of fixed boundaries on highway (edges, lane markers, roadside features).
Change in lateral location	Information indicating that the vehicle has changed location from where it was to a new location in relation to the fixed boundaries of a highway.	Perception of change in location relative to fixed boundaries.
Longitudinal direction	The direction in which the vehicle is heading, either forward or reverse, within a lane.	Perception of environment.
Velocity	Rate of change of distance per unit time.	Perception of movement relative to visual field.
Deceleration	Negative rate of change of velocity.	Perception of environmental cues.
Acceleration	Positive rate of change of velocity.	Perception of environmental cues.
Change in longitudinal direction	Information to the driver that his vehicle has changed directions from forward to reverse or vice versa.	Perception of change in direction.
Lack of visibility (driving past sight distance)	Information indicating rate of speed such that minimum stopping distance exceeds sight distance.	A priori only; no formal transmission.
Regulatory speed	Information indicating maximum and minimum speeds.	Perception of speed limit signs.
Climatological conditions	Information, in advance, indicating a climatological condition that will require modification of the driving task.	Perception of fog, rain, sleet, snow. Perception of warning signs.

[a] See Ref. (*9*) and (*24*).

TABLE 2

DRIVER INFORMATION NEEDS INVENTORY AS RELATED TO SITUATIONAL PEFORMANCE LEVEL[a]

INFORMATION NEED	DEFINITION	VISUAL CONTRIBUTION
Horizontal alignment	Information indicating road curves in the horizontal plane.	Perception of road geometry. Perception of lane markers, edge lines, delineators, etc. Perception of signs (Curve Ahead).
Change in horizontal alignment	Information indicating a horizontal alignment change and degree of change.	Perception of road geometry. Perception of lane markers, edges, delineators, etc. Perception of signs.
Vertical alignment	Information indicating road curves in the vertical plane.	Perception of road geometry. Perception of topography. Perception of signs.
Change in vertical alignment	Information indicating a grade change and degree of change.	Perception of road geometry. Perception of signs.
Surface, climatological	Information indicating road surface condition due to climatological conditions.	Perception of dry, icy, snowy, or wet road surface. Perception of signs (Ice on Bridge, etc.) Perception of conditions that will result in surface change.
Surface, structural	Information indicating road surface structural condition (potholes, bumps, etc.)	Perception of road surface. Perception of signs.
Change in surface type	Information indicating type of surface has or will change.	Perception of change in surface. Perception of signs.
Change in surface structure	Information indicating surface structure has or will change.	Perception of change in structure condition. Perception of signs.
Surface foreign objects	Information indicating that foreign objects are on road surface.	Perception of foreign object. Perception of signs (Falling Rocks, etc.)
Change in surface, climatological	Information indicating that road has or will change.	Perception of road surface change. Perception of signs.
Width of lanes	Information indicating relative lane width.	Perception of lane width via lane markers, etc.
Cross-section change	Information indicating a change in cross section has or will occur.	Perception of changes in cross section. Perception of signs (Divided Highway, etc.)
Median details	Information indicating absence, presence, type and size of median.	Perception of median or lack thereof. Perception of signs.
Shoulder details	Information to the driver about absence or presence of shoulder, and type.	Perception of shoulder. Perception of signs.
Ditches	Information indicating absence or presence of ditches and their location.	Perception of ditches. Perception of signs.

TABLE 2 (Continued)

INFORMATION NEED	DEFINITION	VISUAL CONTRIBUTION
Roadside obstacles	Information indicating absence or presence of roadside obstacles (trees, signs, etc.) and their location.	Perception of obstacles.
Number of lanes	Information indicating quantity of lanes.	Perception of lanes via lane markers. Perception of signs.
At-grade intersection	Information indicating that intersection is approaching and its configuration.	Perception of intersection. Perception of signs.
Railroad crossing	Information indicating crossing, condition, and whether or not occupied or train approaching.	Perception of railroad crossing configuration. Perception of signals and signs. Perception of train.
Special features	Information indicating special features ahead.	Perception of physical signs of the feature. Perception of signs.
Change in road environment	Information indicating that road environment has or will change.	Perception of change in road environment. Perception of signs.
Bridge or tunnel	Information indicating a bridge or tunnel ahead requiring driving change.	Perception of bridge or tunnel. Perception of signs.
Speed of in-lane traffic	Information indicating speed of vehicles in driver's lane.	Perception of lead vehicle and estimation of relative speed to own.
Front gap	Information indicating distance between driver's car and lead car.	Perception of lead vehicle and estimation of gap.
Change in front gap	Information indicating + or — change in gap.	Perception of lead vehicle and estimate of rate of change.
In-lane traffic behavior	Indications of what the lead traffic will do (stop, speed up, turn, etc.)	Perception of lead vehicle taillights, turn signals, etc.
Change in in-lane traffic speed	Indication of the occurrence and rate of change of speed between driver's car and lead car.	Perception of lead vehicle and estimation of rate of change of speed.
Lateral placement of adjoining lane traffic	Indication of presence and location of traffic in adjoining lanes.	Perception of vehicles relative to lane markers, etc.
Speed of adjoining lane traffic	Indication of rate of speed of vehicle(s) in adjoining lanes.	Perception of vehicle speed relative to own speed.
Adjoining lane traffic behavior	Indication of what lead and following vehicle(s) in adjoining lanes will do (stop, speed up, change lanes, etc.)	Perception of vehicle and/or turn signals, lights, wheel orientation.
Adjoining lane traffic lag and change in lag	Indication of remaining gap alongside driver (for passing, lane change, etc.) and change in gap.	Perception of rear vehicle(s) lag and change of lag.
Adjoining lane traffic, passed by and passing	Indication that driver is being passed or passing traffic in adjoining lanes.	Perception of traffic passing. Perception of passing traffic.
Rear gap and change in gap	Indication of distance between driver's rear and rear car's front and change.	Perception of rear gap. Perception of rate of change of rear gap.

Table 2 (Continued)

INFORMATION NEED	DEFINITION	VISUAL CONTRIBUTION
Rear in-lane traffic behavior	Indication of what rear traffic in driver's lane will do.	Perception of rear vehicle(s) turn signals, lights, etc.
Oncoming traffic distance and speed	Indication of how far driver is from oncoming traffic and its speed.	Perception of oncoming traffic, its distance and speed.
Oncoming traffic distance and speed change	Indication of how fast the distance and speed of oncoming cars is changing.	Perception of speed and distance change.
Oncoming traffic behavior	Indication of what oncoming traffic will do (stop, turn, cut in front of, etc.)	Perception of oncoming traffic, turn signals, lights, etc.
Oncoming traffic density	Indication of how many vehicles are oncoming.	Perception of oncoming traffic density.
Distance and rate of closure of cross traffic	Indication of how far driver is from cross traffic and how fast the distance is closing.	Perception of distance to cross traffic. Perception of closure rate. Perception of signs (Intersection Ahead).
Speed and speed change of cross traffic	Indication of speed of cross traffic and speed change.	Perception of cross-traffic speed. Perception of change of cross-traffic speed.
Cross-traffic behavior	Indication of what cross traffic will do (stop, turn, speed up, etc.).	Perception of cross traffic, turn signals, lights, etc.
Level of service	Indication of type of traffic flow ahead (occupancy, density, speed) in terms of driver degree of freedom.	Perception of traffic.
Regulatory	Indication of what driver must do by law, ordinance, or regulation.	Perception of signs, traffic lights, traffic officer, lane markers, behavior of other traffic, color coded curbs, situation.
Warning	Information cautioning driver that a situation is upcoming which may affect his driving behavior.	Perception of signs.
Advisory	Information advising driver of special situation.	Perception of signs. Perception of special situation (toll booth, weigh station, etc.)

[a] See Ref. *(9)* and *(24)*.

This conceptual classification has served a multipurpose function, as follows:

1. To provide a framework for study site selection on which to develop visual information needs as related to characteristics of the facility.
2. To provide a framework on which to establish minimum warranting conditions.
3. To provide a framework on which to establish design guidelines.
4. To provide a framework for the development of priorities for fixed roadway lighting.

The development of the classification has been founded on the belief that roadway lighting designers and administrators need a method of structuring a total lighting program that is related to night driving, warranting conditions, and priorities. The sections that follow describe the conceptualization of such a classification.

TABLE 3

DRIVER INFORMATION NEEDS INVENTORY AS RELATED TO NAVIGATIONAL PERFORMANCE LEVEL [a]

INFORMATION NEED	DEFINITION	VISUAL CONTRIBUTION
Available services	Indicate that services are available and how to obtain them.	Perception of signs. Perception of police car. Perception of service facility.
Direction to intermediate destination	Information telling driver how to find his way to an intermediate destination (city, interchange, stop-over, rest area, etc.)	Perception of signs. Perception of landmarks. Perception of destination (motel, etc.)
Direction to final destination	Information telling driver how to find his way to final destination	Perception of signs. Perception of landmarks. Perception of destination.
Distance to destination	Indication to driver of how far he must travel to reach destination.	Perception of signs.
Alternate route	Indication of different routes available.	Perception of signs.
Road designation	Indication of road number or name; interchange, entrance, exit and turn names or numbers.	Perception of signs.
Compass bearing	Indication of road and vehicle direction (N, S, E, W).	Perception of signs. Perception from environmental clues, sun direction, sense, etc.
Type of road	Information about classification of road driver is on or will be on.	Perception of signs. Perception of road surface, cross section, and alignment.
Geographic area designation	Information about name and/or description of a geographic area.	Perception of signs. Perception of area.
Landmark designation	Information about name or description of a landmark (building, airport, etc.)	Perception of signs. Perception of landmark.

[a] See Ref. (*9*) and (*24*).

Existing Classifications

All state highway systems and most local street and highway systems encompass several classes or types of roadways. At one extreme is the high-speed, high-volume facility carrying through traffic, with no attempt to serve abutting property or local traffic. At the other extreme is the local highway, street, or road that carries low volumes, usually at low speeds, and with a primary function of land access, rather than vehicular movement.

There are two broad classification systems in general use. One involves administrative designation or system classification and signifies the authority over each of the systems by some legislative or administrative body. This system is particularly important in the area of finance, as funds are appropriated at national, state, and local levels in varying amounts depending on system designation.

The second classification system in general use is based on function—movement and access. This system is used by the illuminating Engineering Society to establish recommended light levels. There are two distinct groups in the classification system which reflect these functions. The first involves those facilities with control of access, a condition where the right of owners or occupants of abutting land or other persons to access is fully or partially controlled by public authority. Freeways, interchanges, and expressways fall in this group. The second group involves those facilities without control of access and includes parkways, major arterial streets and highways, collector streets and minor highways, and local streets and roads.

Control of access is employed to expedite flow of traffic on freeways, interchanges, and expressways. Movement is the primary function of the facilities, with access being of secondary importance. On facilities without control of access, geometric and operational controls are used to favor either movement or access depending on the intended function of the facility.

Facilities do not always effectively serve their intended function. Various geometric, operational, or environmental characteristics may influence movement and access, as well as the adequacy of visual communication with drivers. Thus, it is desirable to have a classification system that reflects not only intended function and the degree to which the intended function is served, but also the adequacy of visual communication with drivers. The conceptual classification system proposed herein attempts to reflect those characteristics of traffic facilities that influence visual communication.

Geometric Classification

Geometrics, to a large extent, determine the driving task and the information needs necessary to perform the task safely and efficiently. Geometric design standards are usually related to the functional classification of the facility with higher (better) standards applicable to the higher-class facilities such as freeways. There are conditions, however, that often require higher or lower geometric standards for a given facility. It becomes necessary, therefore, that a given facility be classified on the basis of geometric sufficiency, characterized as follows:

Ideal geometrics—This is seldom achieved except on the higher-class facilities and usually then only in rural areas. Ideal geometrics are considerably superior to minimum design standards.

Superior geometrics—This is often achieved on higher-class facilities and represents standards above minimum.

Minimum geometrics—This category represents minimum design standards for a given facility. A facility designed strictly in accordance with the minimum design controls in most standards would be placed in this category.

Critical geometrics—This represents situations where compromises in design have been made and, due to operational or other considerations, the geometrics no longer meet the minimum conditions for safe operations.

Extreme geometrics—This category applies to conditions that are obviously unsafe for the operating conditions. Extreme grades and horizontal alignment, button-hook ramps, and the like, would be placed in this category.

For each of these categories, a level of complexity or severity is evident (see Fig. 1). Descriptive terms for geometric classification may include quality of access, horizontal and vertical alignment, lane widths, lateral clearances, and number of lanes.

Operational Classification

Various methods have been used in the past to classify traffic facilities on the basis of traffic operations. Figures of merit have ranged from speed and volume to density and capacity, or some combination of all. In an indirect manner, driver comfort, performance, and convenience have been included in the classification. The level-of-service concept is currently used in an effort to describe the operational characteristics for a given facility. This concept involves items such as comfort and convenience.

A similar type of classification is desirable from the night-driving environment standpoint. It is important, however, to include in the operational classification an indication of how well the facility operates to satisfy its intended function.

Ideal operations—This category can be roughly likened to level of service A in the level-of-service concept. This level of operation reflects free-flowing conditions with little, if any, restriction in the ability to maneuver. Volumes are low and speeds are relatively high for the various functional classifications.

LEVEL OF COMPLEXITY OR SEVERITY

GEOMETRIC

IDEAL GEOMETRICS	SUPERIOR GEOMETRICS	MINIMUM GEOMETRICS	CRITICAL GEOMETRICS	EXTREME GEOMETRICS
1	2	3	4	5

OPERATIONAL

IDEAL OPERATIONS	SUPERIOR OPERATIONS	SATISFACTORY OPERATIONS	CRITICAL OPERATIONS	EXTREME OPERATIONS
1	2	3	4	5

ENVIRONMENTAL

IDEAL ENVIRONMENT	SUPERIOR ENVIRONMENT	SATISFACTORY ENVIRONMENT	CRITICAL ENVIRONMENT	EXTREME ENVIRONMENT
1	2	3	4	5

ACCIDENT

EXTREMELY LOW NIGHT ACCIDENT RATES	NIGHT ACCIDENT RATE LOWER THAN DAY RATE	NIGHT ACCIDENT RATE EQUAL TO DAY RATE	NIGHT ACCIDENT RATE HIGHER THAN DAY RATE	EXTREMELY HIGH NIGHT ACCIDENT RATE
1	2	3	4	5

Figure 1. Traffic facility classification.

Superior operations—This category is similar to the first, but somewhat more restricted with slightly lower-than-optimum speeds. The primary function of the facility may be served in a less-than-optimum manner.

Satisfactory operations—This level would be roughly that of level of service C in the level-of-service concept. Operations are stable, but speed and maneuverability are controlled by other vehicles in the traffic stream. Relatively satisfactory operations would be evident.

Critical operations—This level is characterized by excessive limitations on speed and maneuverability. The primary function of the facility is not served in a satisfactory manner. Accidents may occur frequently.

Extreme operations—Operation is unstable, primary and secondary functions of the facility are not served satisfactorily, and speed and volume are not compatible with the facility. Accident experience may be high.

Figure 1 shows the level of complexity or severity assigned to each of the categories. Descriptive terms for operational conditions may include level of service (service volume/capacity), quality of flow (85% speed/design speed), speed differential (85%-15%), and interchanging traffic (number of maneuvers per mile/total volume per mile).

Environmental Classification

One of the greatest needs in evaluating the night-driving environment is a method to consider environmental effects on the driving task. It is recognized that such items as objectionable light sources make the driving task more difficult. Thus, a classification scheme for environmental conditions becomes necessary.

Ideal environment—This level is characterized by little, if any, adjacent land development. There are no objectionable or distracting light sources, and access entrances are at a minimum. Surrounding facilities are not illuminated.

Superior environment—Land-use development is minor, with few distracting light sources and access entrances.

Satisfactory environment—Adjacent land development approximates 50 percent, with some objectionable and distracting light sources. Access points are significant on at-grade facilities but do not predominate.

Critical environment—Land use is high, with frequent distracting and objectionable light sources. Access entrances are numerous on at-grade facilities. Adjacent facilities are lighted.

Extreme environment—Adjacent land is completely developed, with a high number of access entrances on at-grade facilities. Distracting and objectionable light sources predominate. All adjacent facilities are lighted.

The level of complexity or severity assigned to the five categories is shown in Figure 1. Descriptive terms for environmental conditions may include complexity of development, percent frontage devoted to access, effect of sign and environmental lighting, and proximity of development.

Accident Classification

Desirably, the end result of improving the night-driving visual environment will be a reduction in night accident rates and potential for accidents. Past night accident history, therefore, should serve as a means of determining the need for fixed roadway lighting. Using a rating scheme similar to those in previous sections, it is possible to establish a conceptual scale for the inclusion of accident history in the over-all classification concept. The scale representing this inclusion is shown in Figure 1.

Over-All Classification

The geometric, operational, environmental, and accident classification concepts are combined into one unit in Figure 1. Each functional type of facility may be represented by the total scheme, with this type of classification serving as the basic framework for the development and analysis of the field studies.

RESULTS OF FIELD STUDIES

Purpose of Field Studies

Field studies were conducted to develop characteristics of a suitable visual environment. The results of these studies are presented in this section; details of the studies are included in Appendix B.

Visual Information Needs

Data on visual information needs was obtained from three sources:

1. Driver interviews.
2. Questionnaires.
3. Conference sessions.

The driver interviews attempted to isolate visual task problems as related to the driving tasks on the various study sections. In addition, the interviews elicited driver responses regarding the adequacy of visual information and the need for fixed lighting for each of the three basic levels of driving performance.

All comments or responses made by the drivers were classified in accordance with the type of information involved (positional, situational, navigational). The comments were also coded in accordance with the subjects' desires for illumination, or for additional illumination in the case of the lighted sections.

The general analysis procedure was to contrast the responses in the unlighted sections with those from the lighted. The length and complexity of the driving routes were somewhat different, and, therefore, the percentage response takes on greater significance.

Table 4 summarizes the drivers' comments for both the unlighted and lighted arterial study sections in Atlanta and Dallas. It is apparent that the primary use of fixed illumination by the driver is in association with the situational driving tasks. Numerous comments were received on the other two levels of information need, but not to the extent of the situational level. Contrasting the unlighted and lighted responses, a substantially greater number of

TABLE 4

SUMMARY OF RESPONSES FROM THE ARTERIAL STREET STUDY SITES [a]

TYPE OF INFORMATION	UNLIGHTED ARTERIAL			LIGHTED ARTERIAL		
	TOTAL RESPONSES	LIGHTING WOULD BE HELPFUL		TOTAL RESPONSES	MORE LIGHT WOULD BE HELPFUL	
	(NO.)	(NO.)	(%)	(NO.)	(NO.)	(%)
Positional	59	3	5.1	27	0	0
Situational	303	112	37.0	211	15	5.7
Navigational	13	2	9.2	2	0	0

[a] Includes all responses by the drivers, regardless of whether or not a problem existed.

comments dealt with the need for illumination on the unlighted sections than on the lighted sections.

The data were further coded as to the visual task problems that the drivers actually experienced. Tables 5 and 6 summarize these visual task problems for the unlighted and lighted arterials, respectively. For the unlighted arterial sections in Atlanta and Dallas, 128 visual task problems were indicated by the team members. These problems were coded as to the causative factor involved; geometry, operations, environment, and general visibility. In some cases the visual task problems were associated with more than one causative factor.

Environmental conditions, which consisted almost entirely of development lighting adjacent to the facilities, were the most predominant (33.1%) causative factors of visual task problems on the unlighted arterials. Operational conditions were the second most causative factor, with general visibility and geometric conditions ranking third and fourth, respectively.

With regard to specific visual task problems, the ability to see the roadway at a safe distance ahead and intersections comprised more than 50 percent of all visual task problems on the unlighted arterials. These problems resulted from excessive environmental lighting from adjacent development, critical geometry, operational problems and general lack of visibility. Channelization, lane markings, roadside and roadside objects, curbs, and access drives, also were significant visual task problems.

As stated previously, environmental causative factors consisted almost exclusively of excessive lighting from adjacent development. Operational causative factors, with few exceptions, consisted of opposing headlights. Geometric problems involved horizontal and vertical alignment changes and roadway cross section changes. The general visibility factors were mainly inadequate information desired by the drivers.

In comparing the unlighted arterial sections with the lighted sections, it is interesting to note that only 42 visual task problems were indicated on the lighted sections, as compared to 128 on the unlighted. With the exception of the ability to see the roadway at a safe distance, most problems were different. Further, it is interesting to note that the "general visibility" task problems were about the same in number but different in character. For the lighted arterial, 14 of the problems resulted from the lighting system. Nonuniform lighting, distraction by the environment, luminaire glare, and loss of signal-light target value were the more frequent problems. The nonuniform lighting problems came from only one or two sections where lighting was rather erratic, as did the luminaire glare problems. Loss of signal-light target value occurred at intersections where the lighting was mounted low and in close proximity to the signal heads. Other problems were indicated, and although mentioned infrequently, they should not be treated lightly.

The comments and responses from the freeway study sites were similar to those from the arterial sites. Table 7 summarizes all comments from the unlighted and lighted freeway study sites. Again, situational level responses comprised the majority of the total responses. However, both positional and navigational responses were made, especially on the unlighted sections. Navigational responses represented a higher percentage on the freeways than on the arterials.

On the unlighted freeways, a safe view of the roadway ahead was again the most common visual task problem (26.1 percent). Other problems frequently encountered were signs (13.0 percent), ramp entrances (10.9 percent), ramp exits (9.4 percent), merges (8.7 percent), cross-road intersections (5.8 percent), curbs (5.1 percent), and roadside and roadside objects (5.1 percent). Other visual task problems occurred less frequently, but yet must be considered as significant (Tables 8 and 9).

The greatest causative factor of visual task problems on the unlighted freeway sections was critical geometry. This was especially true for safe view of the roadway, ramp exits, and ramp entrances. Operational problems were the second most causative factors, and more often than not involved opposing headlights at narrow medians, high speeds, and high volumes. General visibility restrictions were the third most causative factors; the environment was fourth. It is highly significant that the environment was the least causative factor on unlighted freeways as compared to most causative on the unlighted arterials. On the freeway sections, most environmental buildup was considerably removed from the roadway proper, whereas on

TABLE 5

SIGNIFICANT VISUAL TASK PROBLEMS, UNLIGHTED ARTERIALS

VISUAL TASK PROBLEM	OCCURRENCES (NO.)	OCCURRENCES (% OF TOTAL)	CAUSATIVE FACTOR (NO. OF OCCURRENCES) GEOMETRY	OPERATIONS	ENVIRONMENT	GEN. VISIB.
Roadway	33	25.8	11	2	16	5
Intersections	33	25.8	7	11	10	6
Channelization	11	8.6	1	7		3
Lane markings	11	8.6		8	1	2
Roadside and roadside objects	9	7.0			5	4
Curbs	8	6.3		6	2	1
Access drives	7	5.5		1	4	2
Pedestrians	4	3.1	3	1	1	
Vehicles	4	3.1	1	2	2	
Signs	4	3.1				4
Signals	2	1.6			2	
General visibility	2	1.6		1	1	
All	128	100	23 (17.3%)	39 (29.3%)	44 (33.1%)	27 (20.3%)

TABLE 6

SIGNIFICANT VISUAL TASK PROBLEMS, LIGHTED ARTERIALS

VISUAL TASK PROBLEM	OCCURRENCES (NO.)	OCCURRENCES (% OF TOTAL)	CAUSATIVE FACTOR (NO. OF OCCURRENCES) GEOMETRY	OPERATIONS	ENVIRONMENT	GEN. VISIB.
Roadway	8	19.0	3	1	2	2
Nonuniform lighting	6	14.3				6
Distraction	5	11.9			5	
Luminaire glare	5	11.9				5
Signal lights	4	9.5	1		1	2
Light to dark transition	3	7.1		1		2
Loss of visibility	3	7.1			2	1
Roadside and roadside objects	3	7.1	1			2
Pavement edge	1	2.4				1
Lane markings	1	2.4				1
Signs	1	2.4				1
Glare	1	2.4			1	
Dark to light transition	1	2.4				1
All	42	100	5 (11.9%)	2 (4.8%)	11 (26.2%)	24 (57.1%)

TABLE 7

SUMMARY OF RESPONSES FROM THE FREEWAY STUDY SITES[a]

TYPE OF INFORMATION	UNLIGHTED FREEWAY TOTAL RESPONSES (NO.)	LIGHTING WOULD BE HELPFUL (NO.)	LIGHTING WOULD BE HELPFUL (%)	LIGHTED FREEWAY TOTAL RESPONSES (NO.)	MORE LIGHT WOULD BE HELPFUL (NO.)	MORE LIGHT WOULD BE HELPFUL (%)
Positional	49	5	10.2	26	0	0
Situational	280	104	37.1	74	12	16.2
Navigational	37	19	51.4	6	2	3.3

[a] Includes all responses by the drivers, regardless of whether or not a problem existed.

arterial sections it was usually close and in competition for the driver's attention.

On the lighted freeway sections, no one visual task problem was predominant. Of the 28 problems identified, 45.2 percent were caused by general visibility restrictions, 38.8 percent by critical geometry, 9.7 percent by the environment, and 6.5 percent by operational problems. It is significant to note that luminaire glare was identified as a problem only one time on the lighted freeway sections, and that occurred on a section of US 75 in Dallas where the units were mounted at a height of 30 ft.

The questionnaires, which were completed following each study site run, were tabulated to give general indications of driver attitudes and opinions on informational needs.

TABLE 8

SIGNIFICANT VISUAL TASK PROBLEMS, UNLIGHTED FREEWAYS

	OCCURRENCES		CAUSATIVE FACTOR (NO. OF OCCURRENCES)			
VISUAL TASK PROBLEM	(NO.)	(% OF TOTAL)	GEOMETRY	OPERATIONS	ENVIRONMENT	GEN. VISIB.
Roadway	36	26.1	16	12	8	3
Signs	18	13.0	4	3	2	9
Ramp entrances	15	10.9	7	4		6
Ramp exits	13	9.4	10	2	1	1
Merges	12	8.7	5	4		3
Intersections	8	5.8	4	1	1	3
Curbs	7	5.1	1	5		1
Roadside and roadside objects	7	5.1		1		6
Lane markings	4	2.9		1	1	2
On-ramps	4	2.9	2	2		
Off-ramps	3	2.2	2	1		
Vehicles	3	2.2	2	3		
Delineation	2	1.4				2
Light transition	2	1.4				2
Channelization	2	1.4	2			
Roadway objects	1	.7				1
Glare	1	.7				1
All	138	100	55 (37.4%)	39 (26.5%)	13 (8.8%)	40 (27.2%)

TABLE 9

SIGNIFICANT VISUAL TASK PROBLEMS, LIGHTED FREEWAYS

	OCCURRENCES		CAUSATIVE FACTOR (NO. OF OCCURRENCES)			
VISUAL TASK PROBLEM	(NO.)	(% OF TOTAL)	GEOMETRY	OPERATIONS	ENVIRONMENT	GEN. VISIB.
Glare	4	14.3	1	1	2	2
Ramp exits	4	14.3	4			
Merges	3	10.7		1		2
Signs	2	7.1	1			1
Roadside and roadside objects	2	7.1				2
Pavement edge	2	7.1				2
Roadway	2	7.1	2			
Ramp entrance	2	7.1	2			
Distraction	1	3.6			1	
Light to dark transition	1	3.6				1
Lane markings	1	3.6				1
Off-ramps	1	3.6	1			
On-ramps	1	3.6	1			1
Luminaire glare	1	3.6				1
Non-uniform lighting	1	3.6				1
All	28	100	12 (38.8%)	2 (6.5%)	3 (9.7%)	14 (45.2%)

The following generalizations result from the questionnaires involving arterials:

1. Position within a prescribed lane is dependent on the following elements (listed in descending order):
   (a) Lane lines.
   (b) Edge lines.
   (c) Curbs.
   (d) Position of other vehicles.
   (e) Post-mounted delineation.
   (f) Roadside objects.

2. Geometry changes force drivers to slow unexpectedly on unlighted arterials, but not so much on lighted arterials.

3. Illumination of arterials provides positive identification of roadway direction.

4. Good visibility of curbs and shoulders is deemed necessary on both lighted and unlighted arterials.

5. Intersecting streets often have restricted visibility of traffic on that street, especially if unlighted.

6. Visibility of intersecting traffic in advance of the actual intersection is almost always important and usually very important.

7. The importance of various informational signs is as follows (in descending order):
   (a) Warning signs.
   (b) Regulatory signs.
   (c) Route signs.
   (d) Guide signs.
   (e) Informal signs.

   Route and guide signs could be more important for the non-local driver.

8. Extraneous lighting interferes with the driving task; more so on unlighted arterials than on lighted arterials.

9. Roadside-mounted signs are considered more visible on lighted arterials than on unlighted arterials.

10. Delineation systems are more effective on lighted arterials than on unlighted arterials.

11. Glare from opposing headlights is more severe on unlighted arterials than on lighted arterials.

12. No strong objections were made to roadside-mounted advertising signs and their informational importance was considered as unimportant.

13. Pedestrians are not expected at mid-block but illumination of pedestrian crosswalks is a necessary prerequisite for safety.

Similar generalizations can be drawn from the questionnaires on the freeway sites, as follows:

1. Position within a prescribed lane is dependent on the following elements (listed in descending order):
   (a) Lane lines.
   (b) Edge lines.
   (c) Position of other vehicles.
   (d) Post-mounted delineators.
   (e) Objects along the roadside.

2. Geometric conditions cause drivers to slow unexpectedly, especially on unlighted freeway sections.

3. Complete loss of roadway direction is seldom encountered on freeways.

4. Good visibility of shoulders is a necessary prerequisite for safe driving.

5. Good visibility of the gore area associated with an exit ramp, is always important, regardless of whether or not an exit is to be made.

6. Seeing the merge point of an entrance ramp with the freeway is always important.

7. Detecting changes in exit ramp alignment is important before beginning the exit maneuver.

8. Changes in the number of traffic lanes affect drivers, especially on unlighted freeways.

9. Definition of the median edge is important, especially if traveling in the adjacent lane.

10. The importance of various informational signs is as follows (in descending order):
    (a) Warning signs.
    (b) Regulatory signs.
    (c) Guide signs.
    (d) Route signs.
    (e) Informal signs.

    Guide and route signs could be more important to the non-local driver.

11. There are a few occasions where adjacent developmental lighting interferes with vision, and more so on the unlighted freeway sections.

12. Most overhead-mounted signs are effective from the visibility standpoint, as are roadside-mounted signs. Their effectiveness is slightly better on lighted freeways than on unlighted freeways.

13. Opposing traffic headlights create visual problems on unlighted freeways, and to some extent on poorly lighted freeways. Headlight glare is least noticeable in median lighting situations.

14. Roadside-mounted advertising signs are not especially excessive and their informational value is relatively unimportant.

15. Entrances to on-ramps are seldom visible at an adequate distance on unlighted freeways. It is always important to see the entrance, regardless of whether or not an entrance is to be made.

16. Exits for off-ramps are seldom visible at an adeqaute distance on unlighted freeways, and sometimes on lighted freeways. It is always important to see the exit, regardless of whether or not an exit is to be made.

The conference sessions following the field studies at each geographic site were also fruitful in producing data on visual information needs. It was not the intent of the sessions to reveal new visual task problems or visual information needs, but to solidify the thinking of the entire study team with regard to informational needs in the night driving situation. Priority considerations, also considered, are discussed in a later section.

The first consensus reached by the study team involved the positional information level. All team members stressed the necessity of position information at all times. This information, in the form of lane lines, edgelines, and curb delineation, was considered to be the most critical and most needed information because it held the key to other informational levels. All other tasks at the situational and navigational level depended on the sufficiency of these visual inputs. The subjects insisted that more orderly consideration and accomplishment of the situational and navigational task is possible when these items are readily available. During the driving runs it was observed in too many cases that the drivers had to attend to positional tasks at the sacrifice of the situational and navigational levels. This was due primarily to worn and faded lane lines, absence of edgelines, non-painted curbs, and little contrast between pavement edges and shoulders.

Another consensus of both study teams involved geometrically induced visual task problems. Even as revealed in the interview sessions, both study teams supported the hypothesis that a view of the roadway surface is important at all times. Excessive geometric changes producing restricted longitudinal views of the roadway were considered as among the most critical and frequently occurring visual task situations.

The study teams also reached consensus on the matter of environmental development. Strong emphasis was placed on the detrimental effect of much environmental lighting on performance of the driving task. There was some disagreement, however, as to the characteristics of environmental lighting that made it detrimental. This disagreement obviously stemmed from the fact that on several occasions environmental lighting actually assisted in determining roadway direction on unlighted arterials and directed light onto the roadway surface. Final agreement was reached that environmental lighting is detrimental unless a considerable intensity of light actually reaches the pavement surface, and provided such sources of light are not in themselves distracting or glaring.

Another consensus reached by the study teams involved operations on the various traffic facilities. Higher speeds and higher volumes definitely were considered to be producers of visual task problems. First, it was agreed that opposing headlights introduced periods when vision was virtually obliterated and the problem increased as the number of opposing vehicles increased. Lateral separation of vehicles and fixed lighting, especially median-mounted, were considered the best solutions to the problems. It was also agreed that all driving task accomplishment became more difficult as volumes and speeds increased, mainly because of the competition involved between the various informational needs.

Comfort Benefits

As stated previously, the field studies were also used for measuring subjective driver comfort. Study team members were asked to complete a specially designed questionnaire after driving each study site. Details of the studies are given in Appendix C.

The results of the studies indicate that drivers are comfortable when operating on an illuminated traffic facility, rather than just ". . . less uncomfortable than he would be when driving on a non-illuminated traffic facility."

It was hoped that the comfort studies would provide information allowing for the specification for a hierarchy of discomfort inducers as a function of different types of traffic facilities. However, the limited number of permitted field studies prevented this specification.

Traffic Facility Classification, Warrants, Priorities, and Design Guidelines

The conceptual classification scheme presented in an earlier section was used to classify visual information needs from the field studies and to identify characteristics producing information needs. This basic conceptual scheme, expanded to include the identified characteristics, serves as the over-all basis of the lighting process. This is discussed in later sections. (An alternate scheme for the lighting process is included in Appendix D.)

WARRANTS AND PRIORITIES

Basis for Warrants and Priorities

The discussion of the research approach for this effort indicated a complex interrelationship existing within the over-all design process for roadway lighting. The approach, therefore, involved a fundamental framework of night visual communications efficiency and traffic facility classification.

The nature of the approach and the research problem suggested the need for a large number of field studies throughout the United States. As indicated previously, however, the studies were limited to two geographic areas and eight study sites. This curtailment of studies has limited the total development of driver information needs as well as complete information for weighting warranting factors. It became necessary, therefore, to supplement the field study results with data from the literature and engineering judgment from the research staff. This in itself is desirable, as a broader range of professional expertise and judgment is represented in the final development of warrants, design guides, and priorities. Nevertheless, it is noted that the basic input to the development has come from the field studies.

Requirements for the Suitable Visual Environment

A suitable visual environment for night operations is one in which there is readily available the visual information necessary for a given driving population to safely and efficiently perform the driving tasks under the prevailing night driving circumstances. The primary thrust of the field studies has been to identify those elements of the night-driving visual environment that are necessary for safe and efficient traffic operations. This identification has been necessary for a specification of the requirements for a suitable visual environment to be obtained by fixed roadway lighting. 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.

This section summarizes the significant elements of the night-driving visual environment as determined from the literature and the field studies and suggests basic illumination requirements for accomplishment of the related tasks.

Table 10 summarizes those elements of the total environment that should always be visible to the driver of a motor vehicle. It is not suggested that this summary contains all possible elements for any and every traffic facility; rather it points out those elements considered important by the

TABLE 10

IMPORTANT ELEMENTS OF THE NIGHT-DRIVING VISUAL ENVIRONMENT

ELEMENT	TYPE OF INFORMATION	DESCRIPTION
Roadway geometry	Positional, situational	Perception of the roadway alignment, topography, and cross section at a distance commensurate with travel speed.
Intersection	Situational, navigational	Perception of intersecting roadway ahead commensurate with travel speed.
Channelization	Positional, situational	Perception of markings, curbs, medians, etc., that indicate an assigned path.
Lane markings	Positional, situational	Perception of lane lines, edgelines, centerlines.
Roadside and roadside objects	Positional, situational, navigational	Perception of the environment for dynamic appreciation and recognition of possible hazards.
Curbs	Positional, situational	Perception of curb as an object and guide.
Access drives	Situational	Recognition of curb break, pavement contrast, or other features indicating an access opening.
Pedestrians	Situational	Perception of pedestrian on or adjacent to the roadway, and recognition as a possible conflict.
Vehicles	Positional, situational	Perception of other vehicles on the facility, their location and intended directions relative to own location and movement.
Signs	Situational, navigational	Perception and recognition of signs and their contents.
Signals	Situational	Perception of color and/or orientation of signal heads indicating assignment of right-of-way.
Pavement edge	Positional	Perception of pavement boundaries, contrast between pavement and shoulder or roadside and edgelines.
Delineation	Positional, situational	Perception of roadway delineation as indicative of roadway features.
Special geometric features	Positional, situational	Perception of conflict points, ramp exits and entrances, merges, ramp configuration and direction.
Roadway objects	Situational	Perception of hazardous objects on the roadway at a distance commensurate with travel speed.
Road condition	Situational	Perception of road surface indicating structural and climatic conditions.
Special roadside features	Situational, navigational	Perception of signs, landmarks, etc., indicating an intermediate or final destination.

driver as determined from the research. It is believed, however, that few situations will occur where elements significantly different from those listed will arise.

Many of the elements listed are made adequately visible by vehicle headlights. Also, in some cases no amount of fixed lighting will make elements visible if they are not present or properly maintained (lane lines, edgelines, delineators, etc.). 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—because fixed lighting is an amplifier of these elements. The major problem then is to determine the conditions that justify and quantify fixed lighting to supplement the other elements of the communication system.

It has been apparent from the literature and this research that the primary role fixed lighting can play involves situational tasks. These situational tasks consist primarily of roadway geometry and features including intersections, merges, channelization, curbs, access drives, other vehicles, and pedestrians. These situational features become extremely important when they do not conform to the driver's expectancies.

For basic definition of roadway geometry and features in outlying or residential areas experience has indicated that lighting intensities of at least 0.6 horizontal footcandles will suffice. For special features, such as pedestrians in dark clothing and unexpected roadway objects, intensities considerably above these basic values appear to be necessary. This is especially true as competition between driving task levels increases.

It is suggested that the lighting intensity levels for residential area classification, as recommended by the new American National Standard Practice for Roadway Lighting, be used as basic lighting levels for the various functional classifications and adjusted based on geometric, operational and environmental complexity instead of area classification. In addition, it is suggested that these levels be adjusted for pavement conditions. These adjustments are discussed later herein.

Warrants

The basic classification scheme discussed previously was based on functional, geometric, operational, and environmental conditions that produce visual information needs and modify the efficiency of visual communications with the driver. This basic scheme has been expanded to include a separate classification for each functional type of facility. In addition, the geometric, operational, and environmental parameters that contribute to the informational needs have been defined (Table 11). A fourth classification, accidents, has also been included. Desirable attributes of roadway lighting systems have also been defined (Table 12).

The research agency staff, consisting of six professionals,

TABLE 11

TRAFFIC FACILITY CHARACTERISTICS PRODUCING OR AFFECTING VISUAL INFORMATION NEEDS

GEOMETRIC	OPERATIONAL	ENVIRONMENTAL
	(*a*) Noncontrolled-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 Development type Development setback Adjacent lighting Raised-curb medians
	(*b*) Noncontrolled-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 Deveolpment type Adjacent lighting
	(*c*) Controlled-Access Facilities	
Number of lanes Lane width Median width Shoulders Slopes Curves Grades Interchanges	Level of service	Development Development setback
	(*d*) 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 Cross-road lighting Freeway lighting

TABLE 12

DESIRABLE ATTRIBUTES OF ROADWAY LIGHTING SYSTEMS

(*a*) Noncontrolled-Access Facilities
Uniform lighting on pavement surface
Infrequent spacings to reduce glare
High mounting heights to reduce glare
Median location to reduce headlight glare
Median location to light areas adjacent to roadway
Gradual transitions from light to dark areas
Gradual transitions from dark to light areas
(*b*) Controlled-Access Facilities
Uniform lighting on pavement surface
Infrequent spacings to reduce glare
High mounting heights to reduce glare
Median location to reduce headlight glare
Median location to light areas adjacent to roadway
High-mast lighting in interchange areas
Gradual transitions from light to dark areas
Gradual transitions from dark to light areas

assigned weighting factors to each of the parameters. Justification for the weighting factors came from collective judgment, field study results, and the literature (see "Traffic Control and Roadway Elements (*25*)). An unlighted and lighted weighting factor was assigned to each parameter. The difference between the two factors represents the degree of effectiveness provided by fixed lighting.

Tables 13, 14, 15, and 16 represent the final classification scheme for the various functional facilities considered. The *minimum warranting condition* is the total effectiveness achieved by lighting a traffic facility with an *average rating* of three on the subjective scale of 1 to 5. For example, the minimum warranting condition for continuous arterial lighting (Table 13) is 85 points. These 85 points represent a facility where all geometric, operational, environmental, and accident parameters have a rating of 3 (number of lanes, 6; median width, 10 to 20 ft; development, 30 to 60 percent; night-to-day accident rate, 1.2 to 5; etc.) The rating number 3, multiplied by the unlighted weight for each parameter and summed, minus the rating number 3 multiplied by the lighted weight for each parameter and summed, equals the *minimum warranting number of points*. If a given continuous arterial traffic facility received a 3 rating for each and every geometric, operational, environmental, and accident parameter, the facility would just meet the minimum requirements for lighting. Any combination of ratings that will produce a total of 85 points or more is, of course, warranted. The degree to which the total warranting points exceed the minimum (85 for continuous arterial lighting) serves as the basis for setting priorities.

Justification for Ratings and Weighting Factors

As previously stated, a professional team rated and assigned weightings to each of the classification factors. Justification for the ratings and weightings came from the field studies, literature, and collective judgment of the professional team. Each member of the professional team was provided a transcript of the field study interviews, questionnaire results, and critique sessions. In addition, each team member received a summary of accident rates for various traffic control and roadway element conditions. This summary was prepared from *Traffic Control and Roadway Elements* (*25*). After each team member had a sufficient opportunity to review this information in detail, eight three-hour work sessions were held to assign the ratings and relative weightings. Each assignment was discussed and researched until a consensus of the five-member team was achieved. The following discussion describes the rationale involved in the ratings and weightings developed by the professional team. The ratings are highly judgmental and experience gained through field application may lead to refinement and changes in the ratings and weightings.

Geometric Factors

Number of Lanes.—As the number of operating lanes increases, the ability of the headlights to effectively light the periphery of the roadway is greatly reduced, especially in inclement weather. Identification of the extremes of the roadway is an important element in driver orientation. Normal headlights are able to illuminate the traveled lane and one lane on either side to an acceptable degree. Therefore, with two lanes in one direction (total of four lanes) the driver should have little difficulty in locating the extremes of the roadway and the condition would be ideal—a rating of 1. Three lanes in one direction would result in the drivers in the inside or outside lane being able to identify only one edge of the roadway—not critical, but certainly not ideal. Thus, a rating of 3 seems appropriate. With four or more lanes in one direction, the orientation of the driver becomes a critical factor and the 5 rating is justified.

Lane Width.—As the effective width of the lane is reduced, the problem of tracking becomes increasingly important to the driver. This results in increased concentration on the steering (positional) task and a reduction of a corresponding amount of time that can be devoted to the other elements of the driving task. Therefore, it is important to provide an environment that minimizes the amount of time required to accomplish the nontracking aspects of driving. A lane width of 13 ft or more presents little difficulty and is, therefore, assigned the ideal rating of 1. A lane width of 9 ft or less is critical, as there is little leeway for tracking errors. A rating of 5 has been assigned to this condition. An 11-ft lane is acceptable for most operations and has been assigned a rating of 3, thus completing the scale of ratings for lane width for all classifications.

Number of Legs.—For at-grade intersections, the complexity of operations increases as the number of approach legs to the intersection increases. Ideally, there would be no intersecting legs (i.e., no intersection). Three intersecting legs, such as a T or Y intersection, would be the smallest number of legs possible to have an intersection. This condition has received a rating of 2. Six or more legs, or traffic circles, represent the most complex condition and

TABLE 13

CLASSIFICATION FOR NONCONTROLLED-ACCESS FACILITY LIGHTING

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A-B)	SCORE (RATING X(A-B))
GEOMETRIC FACTORS									
No. of lanes	4 or less	-	6	-	8 or more	1.0	0.8	0.2	______
Lane Width	>12'	12'	11'	10'	<10'	3.0	2.5	0.5	______
Median Openings per mile	<4.0 or one 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	<10%	10-20%	20-30%	30-40%	>40%	5.0	3.0	2.0	______
Curves	<3.0°	3.1-6.0°	6.1-8.0°	8.1-10.0°	>10°	13.0	5.0	8.0	______
Grades	<3%	3.0-3.9%	4.0-4.9%	5.0-6.9%	7% or more	3.2	2.8	0.4	______
Sight Distance	>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	______
						GEOMETRIC TOTAL			______
OPERATIONAL FACTORS									
Signals	all major intersections signalized	substantial majority of intersections signalized	most major intersections signalized	about half the intersections signalized	frequent non-signalized intersections	3.0	2.8	0.2	______
Left turn lane	all major intersections or one way operation	substantial majority of intersections	most major intersections	about half the major intersections	infrequent turn bays or undivided streets	5.0	4.0	1.0	______
Median Width	30'	20-30'	10-20'	4-10'	0-4'	1.0	0.5	0.5	______
Operating Speed	25 or less	30	35	40	45 or greater	1.0	0.2	0.8	______
Pedestrian Traffic at night (peds/mi)	very few or none	0-50	50-100	100-200	>200	1.5	0.5	1.0	______
						OPERATIONAL TOTAL			______
ENVIRONMENTAL FACTORS									
% Development	0	0-30%	30-60%	60-90%	100%	0.5	0.3	0.2	______
Predominant Type 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	>200	150-200'	100-150'	50-100'	<50	0.5	0.3	0.2	______
Advertising or area lighting	none	0-40%	40-60%	60-80%	essentially continuous	3.0	1.0	2.0	______
Raised Curb Median	none	continuous	at all intersections	at signalized intersections	a few locations	1.0	0.5	0.5	______
Crime Rate	extremely low	lower than city aver.	city aver.	higher than city aver.	extremely high	1.0	0.5	0.5	______
						ENVIRONMENTAL 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*	10.0	2.0	8.0	______
						ACCIDENT TOTAL			______

*Continuous lighting warranted

GEOMETRIC TOTAL = ______

OPERATIONAL TOTAL = ______

ENVIRONMENTAL TOTAL = ______

ACCIDENT TOTAL = ______

SUM = ______ POINTS

WARRANTING CONDITION = 85 points

TABLE 14

CLASSIFICATION FOR INTERSECTION LIGHTING

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A-B)	SCORE [RATING X(A-B)]
GEOMETRIC FACTORS									
Number of legs		3	4	5	6 or more (including traffic circles)	3.0	2.5	0.5	____
Approach Lane Width	>12'	12'	11'	10'	<10'	3.0	2.5	0.5	____
Channelization	no turn lanes	left turn lanes on major legs	left turn lanes on all legs, right turn lanes on major legs	left and right turn lanes on major legs	left and right turn lanes on all legs	2.0	1.0	1.0	____
Approach Sight Distance	>700'	500-700'	300-500'	200-300'	<200'	2.0	1.8	0.2	____
Grades on Approach Streets	<3%	3.0-3.9%	4.0-4.9%	5.0-6.9%	7% or more	3.2	2.8	0.4	____
Curvature on Approach Legs	<3.0°	3.0-6.0°	6.1-8.0°	8.1-10.0°	>10°	13.0	5.0	8.0	____
Parking in Vicinity	prohibited both sides	loading zones only	off-peak only	permitted one side only	permitted both sides	0.2	0.1	0.1	____
						GEOMETRIC TOTAL			____
OPERATIONAL FACTORS									
Operating Speed on Approach Legs	25 mph or less	30 mph	35 mph	40 mph	45 mph or greater	1.0	0.2	0.8	____
Type of Control	all phases signalized (incl. turn lane)	left turn lane signal control	through traffic signal control only	4-way stop control	stop control to minor legs or no control	3.0	2.7	0.3	____
Channelization	left and right signal control	left and right turn lane signal control on major legs	left turn lane signal control on all legs	left turn lane signal control on major legs	no turn lane control	3.0	2.0	1.0	____
Level of Service (Load Factor)	A 0.0	B 0-0.1	C 0.1-0.3	D 0.3-0.7	E 0.7-1.0	1.0	0.2	0.8	____
Pedestrian Vol. (peds/hr crossing)	very few or none	0-50	50-100	100-200	>200	1.5	0.5	1.0	____
						OPERATIONAL TOTAL			____
ENVIRONMENTAL FACTORS									
Percent Adjacent Development	0	0-30%	30-60%	60-90%	100%	0.5	0.3	0.2	____
Predominant Development near Intersection	undeveloped	residential	50% residential - 50% industrial or commercial	industrial or commercial	strip industrial or commercial (no circuity)	0.5	0.3	0.2	____
Lighting in Immediate Vicinity	none	0-40%	40-60%	60-80%	essentially continuous	3.0	1.5	1.5	____
Crime Rate	extremely low	lower than city aver.	city aver.	higher than city aver.	extremely high	1.0	0.5	0.5	____
						ENVIRONMENTAL 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*	10.0	2.0	8.0	____
						ACCIDENT TOTAL			____

*Intersection lighting warranted

GEOMETRIC TOTAL = ____

OPERATIONAL TOTAL = ____

ENVIRONMENTAL TOTAL = ____

ACCIDENT TOTAL = ____

SUM = ____ POINTS

WARRANTING CONDITION = 75 points

TABLE 15

CLASSIFICATION FOR CONTROLLED-ACCESS FACILITY (FREEWAY) LIGHTING

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A-B)	SCORE [RATING X(A-B)]
GEOMETRIC FACTORS									
No. of Lanes	4		6		≥8	1.0	0.8	0.2	______
Lane Width	>12'	12'	11'	10'	≤9'	3.0	2.5	0.5	______
Median Width	>40'	24-39'	12-23'	4-11'	0-3'	1.0	0.5	0.5	______
Shoulders	10'	8'	6'	4'	0'	1.0	0.5	0.5	______
Slopes	≥8:1	6:1	4:1	3:1	2:1	1.0	0.5	0.5	______
Curves	0-1/2°	1/2-1°	1-2°	2-3°	3-4°	13.0	5.0	8.0	______
Grades	<3%	3-3.9%	4-4.9%	5-6.9%	>7%	3.2	2.8	0.4	______
Interchange Freq.	4 mi.	3 mi.	2 mi.	1 mi.	<1 mi.	4.0	1.0	3.0	______
						GEOMETRIC TOTAL			______
OPERATIONAL FACTORS									
Level of Service (any dark hour)	A	B	C	D	E	6.0	1.0	5.0	______
						OPERATIONAL TOTAL			______
ENVIRONMENTAL FACTORS									
% Development	0%	25%	50%	75%	100%	3.5	0.5	3.0	______
Offset to Develop	200'	150'	100'	50'	<50'	3.5	0.5	3.0	______
						ENVIRONMENTAL TOTAL			______
ACCIDENTS									
Ratio of night to day accident rates	1.0	1-1.2	1.2-1.5	1.5-2.0	2.0*	10.0	2.0	8.0	______
						ACCIDENT TOTAL			______

*Continuous lighting warranted

GEOMETRIC TOTAL = ______

OPERATIONAL TOTAL = ______

ENVIRONMENTAL TOTAL = ______

ACCIDENT TOTAL = ______

SUM = ______ POINTS

WARRANTING CONDITION = 95 points

have been given the rating of 5. Uniform distribution has been used to assign ratings of 3 and 4.

Median Openings.—The control of access reduces the probability of accidents occurring between through and turning vehicles. As the number of access points is increased, the possibility of conflict increases; therefore, there is a greater need for lighting. Two-way noncontrolled-access streets with median openings at 1,000-ft or greater intervals, and one-way streets, have nearly ideal operation for this condition and therefore are given a rating of 1. A block spacing of 500 ft (i.e., about ten openings per mile) is considered to be about the minimum condition for acceptable street operation and has been assigned a rating of 3. A spacing of 300 ft or less between openings, or a situation with no separator and two-way operation, results in a low quality of street operation. This condition has been given a rating of 5, as a good view of the vehicle maneuvers ahead is critical to safe and efficient vehicle operation. Also, the observed accident rate increases rather slowly up to 15 openings per mile and a great deal more rapidly thereafter (*25*).

Curb Cuts.—The number and length of curb cuts determine the number of vehicle maneuver points available and the degree of operational complexity on noncontrolled-access streets. Less than 10 percent curb openings will not substantially impair traffic operation; therefore, an ideal rating of 1 seems appropriate. When curb openings approach 50 percent, the complexity of operation is critical;

TABLE 16

CLASSIFICATION FOR INTERCHANGE LIGHTING

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A-B)	SCORE [RATING X(A-B)]
GEOMETRIC FACTORS									
Ramp Types	Direct	Diamond	Button Hooks Cloverleafs	Trumpet	Scissors and Left-side	2.0	1.0	1.0	____
Cross-Road Channelization	none		continuous		at interchange intersections	2.0	1.0	1.0	____
Frontage Roads	none		one-way		two-way	1.5	1.0	0.5	____
Freeway Lane Widths	>12	12	11	10	<10	3.0	2.5	0.5	____
Freeway Median Widths	>40	34-40	12-24	4-12	<4	1.0	0.5	0.5	____
No Freeway Lanes	4 or less		6		8 or more	1.0	0.8	0.2	____
Main Lane Curves	<1/2°	1-2°	2-3°	3-4°	>4°	13.0	5.0	8.0	____
Grades	3%	3-3.9%	4-4.9%	5.6.9%	7% or more	3.2	2.8	0.4	____
Sight Dist. Cross Road Intersection	>1000'	700-1000'	500-700'	400-500'	<400'	2.0	1.8	0.2	____
						GEOMETRIC TOTAL			====
OPERATIONAL FACTORS									
Level of Service (any dark hour)	A	B	C	D	E	6.0	1.0	5.0	____
						OPERATIONAL TOTAL			====
ENVIRONMENTAL FACTORS									
% Development	none	1 quad	2 quad	3 quad	4 quad	2.0	0.5	1.5	____
Set-Back Distance	>200'	150-200'	100-150'	50-100'	<50'	0.5	0.3	0.2	____
Cross-Road Approach Lighting	none		partial		complete	3.0	2.0	1.0	____
Freeway Lighting	none		interchanges only		continuous*	5.0	3.0	2.0	____
						ENVIRONMENTAL TOTAL			====
ACCIDENTS									
Rate of night to day accident rates	<1.0	1.0-1.2	1.2-1.5	1.5-2.0	>2.0*	10.0	2.0	8.0	____
						ACCIDENT TOTAL			====

*Complete lighting warranted

GEOMETRIC TOTAL = ____

OPERATIONAL TOTAL = ____

ENVIRONMENTAL TOTAL = ____

ACCIDENT TOTAL = ____

SUM = ____ POINTS

COMPLETE LIGHTING WARRANTING CONDITION = 90 points

PARTIAL LIGHTING WARRANTING CONDITION = 60 points

thus, the rating of 5 is assigned. For the interval between 1 and 5, the percentage of curb openings has been uniformly distributed.

Curves.—The degree of difficulty in negotiating horizontal curves is probably best indicated by accident experience. Curves with curvature in excess of 10° for non-controlled-access streets and 4° for controlled-access facilities have apparent accident rates four to five times those with lesser curvature (*25*). Thus, curves of 10° and 4°, respectively, have been selected as the upper limit of scale and assigned a value of 5. Curves up to 3° for non-controlled-access facilities and ½° for controlled-access facilities have a minimum accident rate. The intermediate ratings have been distributed in general accord with the apparent exponential accident rate with increasing curve severity.

Grades.—The relationship between grade and driving complexity is difficult to establish. The interaction of grade and curvature seems to indicate a linear relation with increasing grades. Below 3° there is little effect of grade and a rating of 1 is appropriate. At more than 7 percent, the effect of grade is very pronounced and the effect is still appreciable on grades of more than 5 percent. Thus, 5 percent was established as the upper bound of the minimum value and is assigned a rating of 3. The remaining gaps were distributed uniformly.

Sight Distance.—The operating speeds on arterial streets and the expected occurrence of conflicts reduce the need for extended sight distance. A sight distance of less than 200 ft would certainly be critical; greater than 700 ft would undoubtedly provide greater information than the driver could effectively use. These two extremes were assigned ratings of 1 and 5, respectively, and the ranges between these extremes have been distributed in a uniform manner. For controlled-access conditions, where higher speeds and less frequent expected conflicts exist, a sight distance of 400 ft has been assigned the critical rating, with 1,000 ft as the ideal. These two extremes were assigned ratings of 1 and 5, respectively, and the ranges between these extremes have been distributed in a uniform manner.

Channelization.—From a geometric standpoint, channelization at intersections and cross-road channelization at interchanges introduces visual task problems for the driver. The less frequent the channelization, the fewer visual task problems will be encountered. Thus, intersections with no channelization have been given the ideal rating of 1, whereas complete channelization on all approaches has been given the rating of 5. Uniform distribution has been used for the ranges between. For cross roads at interchanges, the intersections without channelization have been rated at 1. Continuous channelization of the crossroad has been given the middle rating of 3. Channelization at the interchange intersections only has been rated at 5. This was done to account for the unexpected occurrence of channelization after driving in an area with no channelization.

Median Width.—Median width has been included from the geometric standpoint on controlled-access facilities to describe the level of comfort associated with opposing vehicle separation. A separation of 40 ft or more is sufficient to eliminate interaction between opopsing vehicles and has been assigned the rating of 1. Median widths of less than 4 ft represent the most undesirable condition, rated at 5. Relative uniform distribution has been used for the ranges between.

Parking.—The effect of parking on the need for lighting is directly related to the parking condition on the facility. Five basic conditions were identified and assigned to the rating scale, as follows:

PARKING CONDITION	RATING
Prohibited both sides	1
Loading zones only	2
Off-peak parking permitted	3
Parking permitted, one side	4
Parking permitted, both sides	5

Shoulders.—Although parking is prohibited on controlled-access facilities, there often are emergency situations where vehicles must take refuge adjacent to the through traffic lanes. For this reason shoulders or other areas of refuge are important. The absolute minimum shoulder width that can accommodate a stopped vehicle is approximately 6 ft, and this value has been given the rating of 3. An ideal situation would be 10 ft, assigned the rating of 1. The absence of shoulders represents an absolute critical condition, assigned the value of 5.

Slopes.—For the high-speed operation of controlled-access facilities, it is desirable to provide gentle slopes for errant vehicles. Slopes of 4:1 have been generally accepted as the desirable minimum and thus have been assigned the rating of 3. Slopes of 2:1 have been accepted as the absolute maximum, assigned the value of 5. The ideal rating of 1 has been given to slopes of 8:1 or greater, the current accepted desirable slope.

Interchanges.—Interchange frequency has been included in geometric conditions for controlled-access facilities to represent the geometric design problems that usually result when interchange spacings are close. It is desirable to have at least two miles between interchanges to develop acceleration and deceleration lanes and gentle vertical profiles. This spacing has been rated 3. Any spacing closer than one mile does not provide adequate distance for good geometric development. Thus, spacings closer than one mile have been assigned the rating of 5. The ideal rating of 1 has been assigned to spacings of four miles on an arbitrary basis, but considering that this spacing is possible only in rural areas.

Ramp Types.—This category is included to represent the complexity of various ramp types. The most difficult of all ramp types to negotiate are the scissors and left-side exits. These have been rated at 5. The next most difficult are the trumpet ramps, rated at 4. Button-hook ramps and cloverleafs have been rated at 3, and diamond connections at 2. Direct connections have been given the 1 rating.

Frontage Roads.—The presence or absence of frontage roads on controlled-access facilities determines to a large extent the geometric design of ramps and the extent of activity adjacent to the facility. Two-way frontage roads are the most complex and have been rated at 5. Freeways without frontage roads preclude the problem and thus are rated at 1. One-way frontage roads have been rated at 3.

Operational Factors

Signals.—The presence or absence of traffic signals at major intersections is a major determinant in the need for external illumination. The lack of target value of signs increases the need for identification of the intersection area as well as decreasing the degree of difficulty of the tracking task, thus permitting greater concentration on the operational situation. The descriptors represent the broad spectrum of conditions that exist on noncontrolled-access facilities.

Left-Turn Lane and Signal.—The presence or absence of a left-turn lane and protected signal phase are important contributors to smooth and efficient operation. When these facilities are not provided, the identification of turning vehicles becomes a critical part of the night driving environment. Again, lighting can do little to correct the basic problem except to reduce the complexity of the driving task on the approaches to the critical intersection. As the frequency of these critical intersections increases, the need also increases for a reduction in driving task difficulty to provide more time for concentration on other elements of the task. The descriptor reflects this need.

Median Width.—An increase in the width of the median increases operational efficiency on noncontrolled-access facilities by reducing the effects of opposing headlights and providing an area to "shadow" turning and crossing vehicles. The critical dimension for turning vehicles is 10 ft; for crossing vehicles, 20 ft. Thus, for a median width of 30 ft or more, few serious operational problems exist, and a rating of 1 has been assigned to this condition. A median less than 4 ft in width would provide no space to "shadow" vehicles and, accordingly, has been assigned a rating of 5. Widths in the range of 10 to 20 ft provide space to shadow turning vehicles but not crossing vehicles, a condition considered to be a minimum in this analysis. The remaining ratings were assigned values in accordance with these two conditions. Median width has also been rated for controlled-access facilities based on reduction of headlight glare. A median width of 3 ft would provide for an average lateral displacement between drivers of 10 ft, the most critical separation from an opposing glare standpoint. This width has been assigned the rating of 5. Median width of 12 to 23 ft represents a lateral separation determined as the borderline between comfort and discomfort, and thus has been assigned the value rating of 3. A median width of 40 ft provides for no discomfort from opposing headlights and has been assigned the rating of 1.

Operating Speed.—The speed of operation on noncontrolled-access street systems is a primary determinant in evaluating the need for lighting. Most modern headlights will provide sight distance for safe operation up to 40 mph. Certainly, operating speeds in excess of this must be considered critical, as the use of high beams would be substantially restricted by the interference with opposing vehicles. A speed slightly below the critical value, say 35 mph, should be considered a minimum to provide some margin for error. Below 25 mph, the headlights should provide sufficient advance warning. The speed range for 25 through 45 mph was allocated to the five ratings in 5-mph increments.

Pedestrian Traffic at Night.—An increase in the number of pedestrians crossing the roadway during the hours of darkness increases the relative hazard of driving on the facility. Two hundred crossings per night appeared to be sufficient to justify a rating of 5; no pedestrians would be the ideal condition of 1. The intermediate values were uniformly distributed between these two extremes.

Channelization.—The type of channelization and signal control at an intersection determines the smoothness of operation within the intersection. Five descriptors have been developed to represent this operation. Left- and right-turn lanes with signal control have been rated at 1. No channelization or control received the rating of 5. The remaining descriptors were assigned to the intermediate values.

Level of Service.—Level of service is a method of describing operations on controlled-access facilities and intersections. Level of service may range from A to F, with A representing ideal conditions. This level has been assigned the rating of 1. Levels of service E and F represent critical operations and, thus, have been assigned the value of 5. The intermediate ratings were assigned to levels of service B, C, and D.

Environmental Factors

Percent Developed Frontage—For noncontrolled-access facilities, the percentage of the roadside that is developed affects the number and frequency of vehicle maneuver points. The location of service drives and the identification of vehicles entering or leaving the roadway are factors of considerable importance in the driving task. As the percentage of development increases, the need for additional lighting also increases. The range from 0 to 100 percent development has been distributed over the rating range by subjective judgment. The value of 60 percent as the upper bound of the minimum condition (rating of 3) seems reasonable.

For controlled-access facilities the ratings are basically the same, with the exception of interchange areas. For interchanges the team elected to describe the percent development in terms of the number of quadrants in the interchange that are developed. The rating of 1 has been assigned to the condition of no development and the rating of 5 to all four quadrants developed. Uniform assignment has been made to the remaining ratings.

Predominant Development.—The type of development that most nearly is compatible with noncontrolled-access street operation is undeveloped or backup-type residential development, assigned a rating of 1. The type least compatible with good operation is strip commercial or industrial development, assigned a rating of 5. The other descriptors represent the various levels between these two extremes.

Setback Distance.—The setback distance to the development also affects the type of operation and the degree of interference from the development. For setback distances of 50 ft or less, the operation of vehicles on adjacent property will be essentially parallel to the traffic stream; thus, identification of potentially conflicting vehicles is considerably more difficult. With increasing setback distances, the degree of control of the vehicle entering and leaving the parking area is increased. For setbacks greater than 200 ft, control of access to and from the adjacent areas is complete. The rating of this factor was uniformly distributed between these two extremes.

Advertising or Area Lighting.—When large segments of the roadside are lighted, the roadway can become the darkest portion of the driving environment. This factor must be included in the warranting conditions. When 40 percent or less of the roadside is lighted, the problem will not be critical; when roadside lighting goes beyond 60 percent the problem is drastically increased. The variation from no roadside lighting to continuous roadside lighting can produce serious visual problems in driving. This range has been subjectively rated from 1 to 5.

Raised-Curb Median.—Raised-curb medians have been included as an environmental factor because of the serious interaction between environmental lighting and the transition to the median section. The frequency of these transition problems is represented in the 1 to 5 ratings.

Other Fixed Lighting.—Cross-road approach lighting and freeway lighting have been included in environmental factors for interchanges. It appears reasonable that continuous lighting on cross-roadways or the freeway should contribute to warranting lighting of the interchange. Thus, these conditions have the rating of 5. No lighting of the cross-roadway and freeway has been rated as 1, with partial lighting rated at 3.

Crime Rate.—Reduction in crime rate is one of the often mentioned benefits of fixed roadway lighting on surface streets in downtown urban areas. It appeared desirable, therefore, to include crime rate as a warranting condition. A crime rate equal to the city average has been given the 3 rating. The continuum from 1 to 5 has been rated in relation to the city average. It is suggested that the police department be asked to rate a given facility on this basis for use by the lighting designer.

Accidents

The ratio of night-to-day accident rates has been a traditional measure of the need for roadway lighting. Accident experience should be weighted heavily in any warranting scheme. The ideal condition would be a ratio of 1:1; that is, the total accident rate at night is the same as the total accident rate under daylight conditions. Under normal conditions a ratio of 1.5:1 is not unusual and has, therefore, been assigned a rating of 3. A ratio of 2:1 or more is critical, and lighting should be considered as being warranted for this site. Other ratios have been uniformly assigned to the ratings. Accident rate should include all types and severity of accidents and be expressed in terms of accidents per million vehicle-miles.

Weighting of Factors

The professional research team was used to establish weighting factors for each of the classification elements for lighted and unlighted conditions. Decisions were based on the compilation of accident rate data presented in *Traffic Control and Roadway Elements—Their Relationship to Highway Safety/Revised* (*25*). Where data were not available, the team used a combination of collective judgment and the relative importance of other factors for which data were available.

Priorities

It was previously stated that the extent to which the warranting points exceed the minimum warranting points serves as the basis for setting priorities. Priorities should also be related to the number of people that benefit from a lighting improvement. Therefore, the warranting number for a given traffic facility (unlighted vs lighted conditions) represents the effectiveness that can be achieved through the provision of fixed lighting. Thus, a generalized model for setting priorities would be

$$\mathrm{PI} = \frac{W \times \mathrm{ADT_N}}{C} \tag{2}$$

in which

PI = priority index;
W = warranting number for a given facility;
$\mathrm{ADT_N}$ = night average daily traffic; and
C = cost of the lighting improvement.

This generalized model is developed more fully in the later section on "Cost-Effectiveness."

DESIGN GUIDELINES FOR FIXED LIGHTING

This phase of the research dealt with a detailed review of the current (and proposed) guidelines and practices, and comparison of these guidelines with the needs of the visual environment determined in this research. Specifically, this comparison is made with the "American National Standard Practice for Roadway Lighting" (*13*) and AASHTO's *An Informational Guide for Roadway Lighting* (*10*).

Many effective changes have been made in the latest (1971) revision of the American National Standard Practice for Roadway Lighting as compared to the 1963 edition. In the design section, a concise "design process," or an outline of the steps in lighting design, that should prove helpful to the designer, has been included. However, there is some concern that the design section may be overshadowed by the technical information on luminaire distribution and roadway classification presented prior to the design process. These should be supplemental and thus presented following the design process.

The first step in the design process is:

> Determination from roadway classification and adjacent land use (area classification) of the quantity of light desired, in average horizontal footcandles.

This "step" is supplemented with basically the same suggestions as contained in the 1963 edition, as follows:

> It is important that roadway lighting be planned on the basis of traffic information, which includes the factors necessary to provide traffic safety and pedestrian security. Some of the factors applicable to the specific problem which are to be carefully evaluated are:
>
> A. Type of land-use development (area classification) abutting the roadway or walkway.
> B. Type of route (roadway or walkway classification).
> C. Traffic accident experience.
> D. Street crime experience and security.
> E. Roadway construction features:
>   1. Width of pavement or number of traffic lanes.
>   2. Character of pavement surface.
>   3. Grades and curves.
>   4. Location and width of curbs, sidewalks, and shoulders.
>   5. Type and location of very high-volume driveways.
>   6. Width and location of dividing and safety islands with channelizing curbs.

7. Intersections and interchanges.
8. Underpasses and overpasses.

To this extent, the guideline makes mention of several pertinent traffic considerations, but there is no direction as to how these are to be scaled. There is the implication that roadway lighting serves the basic purpose of traffic safety (prevention of accidents), whereas this research effort has demonstrated the informational aspects of lighting. It is logical that improvement in the communication system will improve efficiency of traffic operation, and traffic safety is a by-product of efficiency.

Constructively, the roadway classification system should be formulated as shown previously under "Warrants and Priorities" so that the important geometric, operational, and environmental parameters may be scaled or otherwise quantitatively considered. This classification scheme will facilitate the selection of lighting levels, considering a combination of quantitative and qualitative measures of factors relating to the character of the roadway, the traffic, and the informational system.

Illumination Levels

The recommended illumination levels included in the American National Standard Practice for Roadway Lighting (1972) do not differ greatly from the 1963 edition. The new recommendations are as given in Table 17, as described in the new classification scheme as follows:

1. CLASSIFICATION OF ROADWAYS AND AREAS

1.1 *Roadway and Walkway Classifications.*

(a) *Major*—The part of the roadway system that serves as the principal network for through traffic flow. The routes connect areas of principal traffic generation and important rural highways entering the city.

(b) *Collector*—The distributor and collector roadways serving traffic between major and local roadways. These are roadways used mainly for traffic movements within residential, commercial and industrial areas.

(c) *Local*—Roadways used primarily for direct access to residential, commercial, industrial, or other abutting property. They do not include roadways carrying through traffic. Long local roadways will generally be divided into short sections by collector roadway systems.

(d) *Expressway*—A divided major arterial highway for through traffic with full or partial control of access and generally with interchanges at major crossroads. Expressways for noncommercial traffic within parks and park-like areas are generally known as parkways.

(e) *Freeway*—A divided major highway with full control of access and with no crossings at grade.

(f) *Alley*—A narrow public way within a block, generally used for vehicular access to the rear of abutting properties.

(g) *Sidewalks*—Paved or otherwise improved areas for pedestrian use, located within public street rights-of-way which also contain roadways for vehicular traffic.

(h) *Pedestrian Ways*—Public sidewalks for pedestrian traffic generally not within rights-of-way for vehicular traffic roadways. Included are skywalks (pedestrian overpasses), subwalks (pedestrian tunnels), walkways giving access to park or block interiors, and crossings near centers of long blocks.

1.2 *Area Classifications.*

(a) *Commercial*—That portion of a municipality in a business development where ordinarily there are large numbers of pedestrians and a heavy demand for parking space during periods of peak traffic or a sustained high pedestrian volume and a continuously heavy demand for off-street parking space during business hours. This definition applies to densely developed business areas outside of, as well as those that are within, the central part of a municipality.

(b) *Intermediate*—That portion of a municipality which is outside of a downtown area but generally within the zone of influence of a business or industrial development, characterized often by moderately heavy nighttime pedestrian traffic and a somewhat lower parking turnover than is found in a commercial area. This definition includes densely developed apartment areas, hospitals, public libraries, and neighborhood recreational centers.

(c) *Residential*—A residential development, or a mixture of residential and commercial establishments, characterized by few pedestrians and a low parking demand or turnover at night. This definition includes areas with single-family homes, townhouses, and/or small apartments. Regional parks, cemeteries, and vacant lands are also included.

TABLE 17

RECOMMENDATION FOR AVERAGE MAINTAINED HORIZONTAL ILLUMINATION

	FOOTCANDLES (LUX) FOR AREA CLASSIFIED AS		
CLASSIFICATION	COMMERCIAL	INTERMEDIATE	RESIDENTIAL
Vehicular roadways:			
Freeway [a]	0.6 (6)	0.6 (6)	0.6 (6)
Major and expressway [a]	2.0 (22)	1.4 (15)	1.0 (11)
Collector	1.2(13)	0.9 (10)	0.6 (6)
Local	0.9 (10)	0.6 (6)	0.4 (4)
Alleys	0.6 (6)	0.4 (4)	0.2 (2)
Pedestrian walkways:			
Sidewalks	0.9 (10)	0.6 (6)	0.2 (2)
Pedestrian ways	2.0 (22)	1.0 (11)	0.5 (5)

[a] Both mainline and ramps.

Although this classification scheme is more specific than that presented in the 1963 edition, it lacks a direct relationship to the effects of roadway, traffic, and environmental conditions.

It is believed that a more specific relationship between illumination levels and roadway classification and the modifying conditions can be achieved by using the classification system presented previously in this report. It is suggested that basic illumination levels be established for the various types of roadways and a scaling system be devised to increase the illumination level based on the modifying conditions. Logically these basic illumination levels would be the same as those presented for the residential area in the American National Standard Practice for Roadway Lighting (1971), as given in Table 18. These are considered to be the basic values, because they normally represent a minimum of the modifying conditions (roadway, traffic, and especially environmental conditions).

The adjustment of the minimum values upward to compensate for existing conditions would be accomplished on the basis of a detailed study of those conditions on the roadway in question. The study guide is based on the previous classification scheme, in which the illumination level for a particular roadway is determined by comparing the rating of the roadway in question to the rating of the minimum conditions that justify lighting. This minimum condition was established by rating the facility classification to minimum or average conditions in the four classification categories. Therefore, the base rating is 85 for continuous arterial lighting and illumination levels would be increased by the ratio

$$\frac{\text{Warranting points for facility}}{\text{Basic rating of 85}} \qquad (3)$$

For example, consider an old major arterial through a highly developed area with high traffic density and high speeds, which may have 127 total warranting points. By using this value and the base value of 85, the required illumination level may be computed as $\frac{127}{85}(1.0) = 1.55$ hfc.

Another important factor in establishing an illumination level for a given facility is the pavement reflectance. It is well recognized from the literature and lighting practices that pavement condition determines the actual luminance patterns for a given lighting system. Therefore, road-surface luminance provides the most accurate measure of the effective light in a lighting system. This is acknowledged by some lighting codes, which usually specify two illumination values for the same classification of facility—one for a "light" road surface and another for a "dark" surface. Other codes specify one illumination value and prescribe a suitable increase in the specified value if the road surface under consideration is dark.

The International Recommendations for the Lighting of Public Thoroughfares (*26*) gives approximate ratios of the average road-surface luminance in cd/m^2 to the average illumination in lux. These ratios are 0.06 (dark surfaces) and 0.11 (light surfaces) for semi-cut-off lighting units, the most predominantly used in U.S. lighting practice. These values, when converted to ratios of road-surface luminance in footlamberts to average illumination in footcandles, are 0.19 and 0.36, respectively, for dark and light pavements.

These factors can be applied to the design level of illumination to compensate for pavement surface properties. A pavement classification scheme similar to that for previous traffic facility classifications can be used, as follows:

EXTREMELY LIGHT PAVEMENT	ABOVE AVERAGE PAVEMENT	AVERAGE PAVEMENT	BELOW AVERAGE PAVEMENT	EXTREMELY DARK PAVEMENT
1 (0.34)	2 (0.31)	3 (0.27)	4 (0.23)	5 (0.19)

TABLE 18

RECOMMENDATIONS FOR AVERAGE MAINTAINED HORIZONTAL ILLUMINATION

ROADWAY CLASS	FOOT-CANDLES	(LUX)
Freeways, including major interchanges	0.6	(6.0)
Primary arterials, expressways, major highways	1.0	(11.0)
Secondary arterials, major collectors, secondary highways	0.6	(6.0)
Minor collectors, minor commercial roads	0.4	(4.0)
Local roads, streets, alleys	0.2	(2.0)

By assigning a unit value to the average pavement condition, a weighted multiplier for each of the five pavement classifications can be established, as follows:

EXTREMELY LIGHT PAVEMENT	ABOVE AVERAGE PAVEMENT	AVERAGE PAVEMENT	BELOW AVERAGE PAVEMENT	EXTREMELY DARK PAVEMENT
0.80	0.90	1.0	1.2	1.4

To use the multiplier, the illumination value determined previously and adjusted for geometric, operational, and environmental conditions is then corrected by use of the multiplier. For example, in previous paragraphs a value of 1.55 horizontal footcandles was determined. This value is for average pavement conditions. For extremely dark pavements this value would be increased by the factor 1.4, or the required illumination would be $(1.55)(1.4) \doteq 2.17$ hor. ft-cd. It is suggested that the required level of illumination as determined in this process be rounded up to the nearest 0.10 hor. ft-cd (2.20 in this case).

There is no doubt that this scheme represents a simplification of pavement luminance, but it appears to be reasonably responsive to the factors that relate significantly to the informational needs of the driver. This is sufficient, considering the lighting designer has little control over pavement reflectance.

At some point, consideration should be given to controlling and/or providing sufficient light in the border areas. Because a distance of 30 ft from the traveled way has been established as a width of frequent excursions from the roadway, it is recommended that an illumination level of not less than 1/10 the design level be provided within 30 ft of the pavement edge, at a uniformity of 3 to 1.

Uniformity

Uniformity of light distribution has proven to be at least equally as valuable as the illumination level in providing a satisfactory night-driving environment. The Standard

Practice recommends an average-to-minimum ratio of 3:1, whereas AASHTO specifies 3:1 or 4:1. The 3:1 values are acceptable for normal street and roadway lighting, but it would be desirable to reduce this value to 2:1 for high-mast area lighting applications in interchange areas (*27*).

Luminaire Mounting Height

The new standard practice, as well as the AASHTO Guide, recognizes the value of increased mounting heights (40 to 60 ft) with the advent of larger and more efficient light sources. It is pointed out that higher mounting heights may reduce glare, depending on the light distribution from the luminaire.

High-mast lighting is recognized as having several advantages at interchanges and other sites where area lighting is appropriate. Among the advantages are fewer poles, possible lower over-all system cost, increased safety, and increased comfort through improved uniformity and reduced disability veiling brightness (DVB).

A later section deals with the design practices recommended for high-mast lighting.

Luminaire Spacing and Location

Although there are a number of environmental and roadway factors that affect the spacing and location of luminaire supports, the spacing is mainly dependent on the basic design criteria, average intensity, and uniformity. Two basic approaches now being used in spacing determination are a design standards approach and a computational approach. In the design standards approach the design agency establishes typical spacings of specific luminaire types for various design applications, based on previous experience or testing. This approach is given in Table 19. These standard spacings are applied generally, and adjustments to fit roadway conditions are generally checked using a plastic overlay iso-footcandle curve to ensure adequate light coverage.

The design standards approach must be well supported by job specifications that require a specific distribution of light on a section of the roadway equal to the spacing of luminaires. Further, a positive sampling and testing procedure must be established to ensure that the equipment meets the specifications.

The computational approach is well documented in the 1963 Standard Practice, and remains unchanged in the proposed revision. The basic formula for this approach is

$$\text{Average illumination (footcandles)} = \frac{LL \times CU \times LMF}{S \times W} \quad (4)$$

in which

LL = Lamp lumens at replacement time;
CU = Coefficient of utilization (the percentage that can be utilized on the specified roadway using a given luminaire);
LMF = Luminaire Maintenance Factor (percentage of initial light output remaining after depreciation because of dirt accumulation and deterioration);
S = Luminaire spacing, in feet; and
W = Width of street, in feet.

In some areas, other correction factors, such as temperature factors, may be included.

The uniformity of illumination is computed from data taken from an iso-footcandle diagram for a given type of luminaire.

The computational procedure is a rational approach to design, but its rationality is dependent on the reliability of input data: specifically, the coefficient of utilization and the iso-footcandle diagram. Sometimes utilization curves and iso-footcandle diagrams are typical curves for a given IES-type luminaire. In other cases, the photometric data used in preparation of these data sources are collected by the manufacturer under well-controlled laboratory conditions. Allowances are not made for the loss in control of conditions when the equipment is placed in general service.

More realistic design data can be achieved by developing utilization curves and iso-footcandle diagrams from actual field installations or full-scale field laboratory testing. In any case, a lighting project should have specific performance criteria supported by a testing program to ensure job quality.

TABLE 19

TYPICAL DESIGN STANDARDS FOR FREEWAY-TYPE FACILITIES, MEDIAN OR HOUSE-SIDE ARRANGEMENT

NO. OF LANES	LIGHT SOURCE	TYPE OF LUMINAIRE	MOUNTING HEIGHT (FT)	SPACING (FT)
4	400 W MV	Type II, medium distribution	40	200
6 to 10	1000 W MV	Type III, medium distribution	50	250

Luminaire Location

The location of luminaires with respect to the roadway has been given considerable attention in both the Standard Practice and the AASHTO Guide. Emphasis is placed on the need to place the support as far from the travel lanes as is practicable. Further, it is recognized that most luminaires perform better when they are not mounted over the roadway; the uniformity of illumination is improved and glare is reduced when the luminaire is mounted at the edge of the lane or over the shoulder.

Both design guides recognize the value in location and base design of luminaire supports to reduce the probability of collision, and to reduce the severity of impact when a collision does occur. Most sources of information recognize the need for breakaway support bases when vehicle operating speeds exceed 30 mph.

Design of High-Mast Lighting

Neither the Standard Practice nor the AASHTO Guide provide any detail in the guidelines for design of high-mast lighting, but a design procedure is presented by Rowan and Walton (*27*). This procedure, however, is based largely on the use of iso-footcandle curves produced from field laboratory tests and judgment or experience. Considerably more rationale is contained in the procedure described in this section.

Illumination Levels

The Standard Practice and the AASHTO Guide do not specify illumination levels for interchanges other than for the freeway in general, except that the Standard Practice states:

> Intersecting, converging, or diverging roadway areas require higher illumination. The illumination within these areas should at least be equal to the *sum* of the values recommended for each roadway which forms the intersection.

This guide does not take into consideration the design and operational conditions; therefore, it is considered more appropriate that the illumination level for interchanges be determined on the basis of the rating scheme previously presented for interchanges.

Achieving a specified illumination level is a function of mounting height, type of light source, type of luminaire or floodlight, and number of luminaires or floodlights in a system (system refers to the assembly on a single mast). It is possible to estimate a trial number of units in a system by a computational process involving total lamp lumens, a coefficient of luminaire efficiency, and the area to be covered, but experience is extremely valuable in this process. In any case, the designer will likely determine by trial and error the number of units required to provide a given illumination level.

Location and Spacing of Masts

Preliminary spacing of masts in the interchange area should be made on a maximum spacing-to-mounting height ratio of 5:1 if the objective is to achieve the same cut-off characteristics that are achieved using medium distribution luminaires in continuous lighting. Adjustments to spacing should be made on the basis of location criteria and computational procedures of illumination by the point-by-point method discussed later.

Certain considerations must be recognized in the location of masts in order to achieve the greatest effectiveness from the lighting system, as follows:

1. Masts should be located so that the driver's line of sight is not directly toward the light source in the range of 1,500 ft to two mounting heights from the source. Preferably, the line of sight would not be above the lower third-point of the mast while the line of sight is within 10° either side of the mast.
2. Masts should be located so that the light source will not at any time be in the direct line of sight with signs, especially overhead signs, and other visual communication media.
3. Masts should not be placed at the end of long tangents or in other vulnerable locations where there is an appreciable probability of collision. If such a location is necessary, adequate impact attenuation should be provided.
4. Masts are desirably located such that the highest localized levels of illumination fall in the traffic conflict areas, such as ramp terminals. Otherwise, masts should be located a sufficient distance from the roadway to position the greatest uniformity of illumination on the pavement surface. This is done using plastic overlays of iso-footcandle curves of the light units to be used. This will normally result in the masts being placed a sufficient distance from the roadway to virtually eliminate the probability of collision.

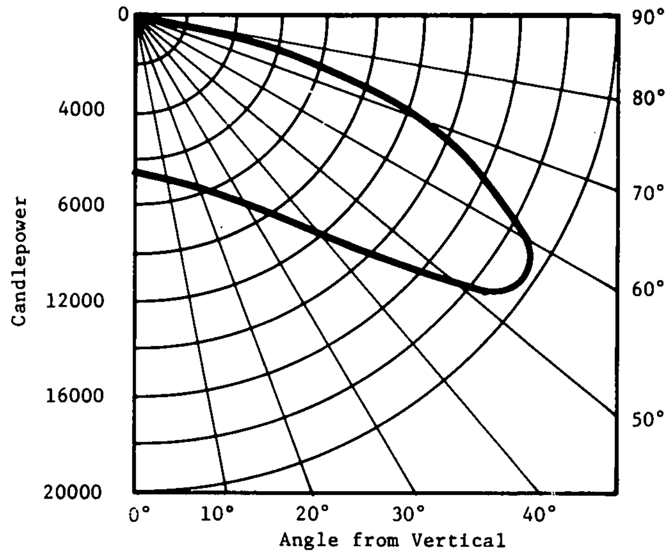


Figure 2. Typical candlepower distribution curve.

Illumination Computational Procedures

Following the preliminary location and spacing of masts and the initial selection of the number of units on each mast, it is necessary to check the distribution of illumination against the established criteria. The most rational approach to this check process is by computation of illumination using a point-by-point procedure. To facilitate computations, the entire interchange area is superimposed with grid lines; intervals of 25 ft are desirable if a computer is used, whereas 50-ft intervals are more appropriate for hand calculations.

The point-by-point computation process uses a candlepower distribution curve (Fig. 2). Such curves normally are developed for single-unit Type V luminaires, in which case they must be multiplied by the number of luminaires in the system. Such a curve can be developed for all symmetrical high-mast systems, whether they are made up of Type V units or individual floodlights arranged in a symmetrical pattern.

The illumination in horizontal footcandles at a grid point resulting from one high-mast assembly can be computed using

$$E_{H} = \frac{CP \cos \theta}{d^2} \tag{5}$$

in which

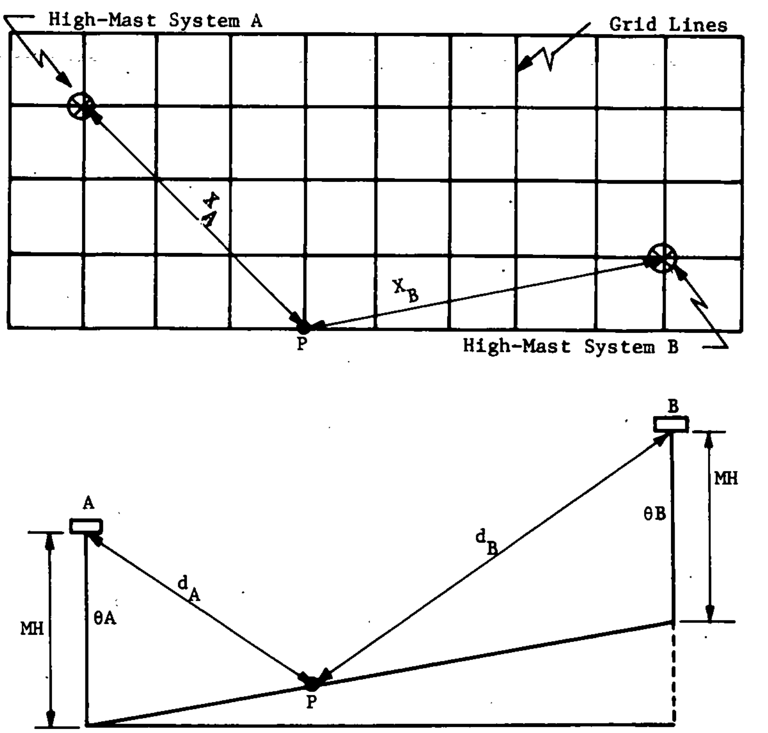
E_H = Illumination at the point, in horizontal footcandles;
CP = Candlepower at angle θ, in lumens;
θ = The angle from the vertical axis through the system to the point in question (Fig. 2); and
d = The distance from the light source to the point in question (Fig. 3).

Then, the total illumination at each of the grid points is the sum of the contributions of illumination from the high-mast assemblies within an effective range of the point in question. This process is shown in Figure 3.

Once the amount of illumination is computed for all of the grid points, an iso-footcandle diagram may be drawn for the entire interchange area. This will facilitate an overall appraisal of the illumination design.

For a more specific appraisal the designer should plot an illumination profile for each section of roadway in the interchange. For wider roadways, it may be necessary to plot two or more profiles to fully represent the traveled way. These profiles are plotted using the contour values and contour spacings along the roadway, or by interpolation between the illumination values at the grid points. If computer techniques are used, the latter is the more adaptable process. From the illumination profile, the average illumination values and uniformity ratios are computed. By comparing the average illumination and uniformity ratios with the previously established criteria, the spacing of masts and/or number of units on each mast may be adjusted. The computational process is repeated until the desired criteria are achieved.

The major weakness in the point-by-point design process is the reliability of the input photometric data, as in the case of computational procedures for continuous lighting. The candlepower distribution curve is developed under controlled laboratory conditions. There is some preliminary indication from unpublished research that the loss from laboratory to field installation is on the order of 25 percent. Therefore, it seems justified that the designer consider re-



$$d_A = \sqrt{\bar{X}_A^2 + (\text{Elev. A} - \text{Elev. P})^2} \quad \text{and}$$

$$d_B = \sqrt{\bar{X}_B^2 + (\text{Elev. B} - \text{Elev. P})^2}$$

$$\text{Then } EH_P = \frac{CP_{\theta A} \cos \theta_A}{\bar{X}_A^2 + (\text{Elev. A} - \text{Elev. P})^2} + \frac{CP_{\theta B} \cos \theta_B}{\bar{X}_B^2 + (\text{Elev. B} - \text{Elev. P})^2}$$

$$+ \cdots$$

Figure 3. Illustration of point-by-point process of illumination computations.

ducing the candlepower values by 25 percent unless there is evidence that he can be assured of achieving the light output indicated by the candlepower distribution curve.

COST-EFFECTIVENESS

The purpose of this section is to discuss and analyze the role of cost-effectiveness in (a) establishing the need for fixed roadway lighting, (b) setting priorities for fixed lighting projects, and (c) evaluating alternative designs of lighting.

A state-of-the-art review was made with respect to different methods of economic analysis that could be used in determining needs, choosing lighting designs, and setting priorities. These methods were: the cost-effectiveness method, the cost-of-time method, the benefit-cost method, the rate-of-return method, and the total-transportation-cost method. All except the cost-effectiveness method use monetary evaluations of effectiveness and could be used to establish needs, determine best designs, and set priorities, *if* lighting effectiveness could be measured in dollar terms. Lighting needs would be defined as all projects that give more benefits than they cost. The choice of best designs and priorities would be determined simultaneously by choosing those projects and project increments that maximized the net dollar benefit from lighting.

Unfortunately, it is not possible, with the current state of the art, even to measure in physical units the effects on motorists of different types and degrees of lighting in different situations, much less to measure the value of changes in these physical units in dollar terms. Therefore, it was decided that the current state of the art limits economic analysis to the cost-effectiveness method employing the equal-cost or equal-effectiveness criteria, and augmented by the decision-maker's judgment.

Cost-effectiveness analysis can be used to help choose the preferred lighting design for different situations in which lighting is warranted. It cannot be used to determine lighting needs, even though information developed in the process of choosing designs and setting priorities should help the decision-maker become better aware of lighting needs. Cost-effectiveness analysis also can be used to help set priorities; the recommended cost-effectiveness method for setting priorities is discussed in the next section of this chapter. The purpose of this section is to discuss how the cost-effectiveness method, together with judgment, can be used to select the preferred lighting design for different situations that warrant lighting.

In general, the cost-effectiveness procedure recommended for selecting a design for a particular situation is as follows:

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 in a table and, using this summarized information together with judgment, choose the "best" design. (This "best" design, together with its effectiveness and cost, is the design that is used in priority determinations.)

The cost-effectiveness procedure recommended for comparing alternative designs uses procedures developed by Cassel and Medville (*28*), and makes use of forms (Figs. 6, 7, 8) developed by them. Five forms are to be completed for each warranted situation (e.g., each continuous section of roadway, interchange, intersection). Each specific facility is assigned an Identification Number, which appears on each form corresponding to that facility. Form 1 (Fig. 4) gives identifying characteristics and design variables, and also has a space for identifying the "best" design, chosen at the completion of the analysis. Form 2 (Fig. 5) is for summarizing the cost and effectiveness of each feasible design; one line applies to each feasible configuration, each assigned an identifying number. Form 3 (Fig. 6) summarizes the characteristics of each feasible configuration. Form 4 (Fig. 7) provides spaces

FORM 1

Identification Number: __________

SUMMARY

(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 (ADT_N):
(9) Warranted illumination level, ave. maintained footcandles (w):
(10) Calculated lighting effectiveness or total warranting points (E):
(11) Multiplier = $(E \times ADT_N \times L)/(n \times w)$:
(12) Analysis period (years):
(13) Interest rate (%):
(14) Desired uniformity ratio(s):

Best Design

(15) Configuration number:
(16) Priority index(es):
(17) Annual cost:
(18) Ave. maintained footcandles:
(19) Uniformity ratio(s):

Figure 4. Summary form.

FORM 2

COST AND EFFECTIVENESS SUMMARY FORM

IDENTIFICATION NUMBER:_________

			ANNUAL COST[c]					EFFECTIVENESS				
											Priority Index[d]	
(1) Configuration Number	(2) Circuit Number[a]	(3) Initial Capital Cost	(4) Equivalent Capital[b]	(5) Maintenance and Power	(6) Sub-total (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. Cost and effectiveness summary form.

FORM 3

ROADWAY LIGHTING CONFIGURATION SUMMARY FORM

IDENTIFICATION NUMBER:________

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

[a]HB = horizontal burning
SE = standard enclosed

Figure 6. Roadway lighting configuration summary form.

FORM 4
EQUIPMENT SPECIFICATION AND COST SUMMARY FORM
Identification Number:__________

Item	Configuration Number			
	Circuit Number[a]			
a. Basic Data				
1. Lamp Type				
2. ASA designation				
3. Initial Lumens				
4. Wattage				
5. Mounting Height (feet)				
6. Overhang (feet)				
7. Luminaire Type				
8. Light-Distribution Type				
9. Arrangement				
10. Spacing (feet)				
11. Average Horizontal Footcandles				
12. Minimum Footcandles				
13. Uniformity Ratio				
14. Total kw Per Lamp				
15. Lamps per Mile				
16. Distribution System				
17. Lamps/circuit				
18. Burning hours per year				
19. Adjustment Factor[b]				
b. Cost Summary (dollars)				
OMC I: User Ownership and Maintenance				
1. Initial Cost				
2. Equivalent Annual Cost				
3. Annual Maintenance Cost				
4. Annual Power Cost				
5. Total Annual Cost				
OMC II: User Ownership, Utility Maintenance				
6. Total Annual Cost				
OMC IIIa: Utility Ownership and Maintenace, Aggregate				
7. Total Annual Cost				
OMC IIIb: Utility Ownership and Maintenance, detail				
8. Total Annual Cost				
9. Annual Cost/Average Horizontal Footcandle (OMC I)				

Figure 7. Equipment specification and cost summary form.

Item	Configuration Number			
	Circuit Number			
	c. Non-Distribution and Control			
1. Pole: Material Arm Length (feet)				
2. Wood Pole Bracket: Material Arm Length (feet) Bracket Type Slipfitter (inches)				
3. Luminaire: Description				
4. Ballast: Description				
	d. Distribution and Control			
1. Cable/conduit a. Distribution Type Feet/Circuit b. Connection Type Feet/Circuit c. Pole Type Feet/Pole				
2. Time Controls a. Photoelectric control and receptacle b. Time Switch				
3. Transformers a. Constant Current Type Primary Volts Secondary Amps KW Rating Quantity/Circuit b. Distribution Low Voltage High Voltage KVA Rating Quantity/Circuit c. Hanger Iron				

Item	Configuration Number			
	Circuit Number			
	d. Distribution and Control (cont)			
4. Group-Control Equipment				
a. Multiple Relay				
Type				
Quantity				
b. Protective Relay				
Type				
Quantity				
c. Remote-Control Oil Switch				
Type				
Quantity				
d. Multiple Control Switch				
Type				
Quantity				
e. Power-Factor-Correcting Capacitor				
Type				
Quantity				
f. Capacitor Mounting Brackets				
g. Potential Transformer				
Type				
Quantity				
h. Time-Delay-Lockout Relay				
Type				
Quantity				
i. Fuse Cutout				
Type				
Quantity				
j. Other (specify)				

[a] There may be several circuits for each configuration number.

[b] $\frac{\text{Lamps/mile}}{\text{Lamps/circuit}}$

Figure 7 (Continued)

for listing the equipment and cost of each circuit that is considered for each feasible configuration; each configuration may have one or more circuits. The cost summary information in section b of Form 4 (Fig. 7) is taken from Form 5 (Fig. 8), the detailed cost calculation form. A separate Form 5 is completed for each different circuit appearing in Form 4. (For a complete description of these forms, for equipment and cost information, and for several example calculations, see Cassell and Medville [*28*].) Forms 4 and 5 are in terms of costs per mile of continuous lighting, but can easily be modified to calculate the cost per facility; or, the cost per mile can be calculated and multiplied by the number of miles per facility. The use of these forms is discussed more fully in the following.

FORM 5
COST DATA FORM
Identification Number:______
Configuration Number:______
Circuit Number:______

Completion Instructions:

Ownership/Maintenance Configuration (GMC)	Complete Lines
I.	1 through 45
II.	1-26, 31-35, 46, 47
IIIA.	48, 49
IIIB.	42-44, 50-55

Equipment-Specification Summary:

i	distribution cable / circuit	=	______
ii	connection cable / circuit	=	______
iii	poles per mile	=	______
iv	adjustment factor	=	______
v	total kw per lamp	=	______
vi	burning hours per year	=	______

OMC I: User Ownership and Maintenance

a. Initial Costs

(1) Per Pole

	Unit Cost (dollars)	
	Equipment	Labor
1. Pole		
2. Foundation		
3. Luminaire		
4. Lamp		
5. Bracket Arm		
6. Ballast		
7. Photoelectric Control		
8. Cable		
Total		

9. Total initial cost per pole $______

10. Initial cost per mile of pole items $______

(2) Per-Circuit Distribution

(a) Circuit

Item	Cost per Foot (dollars)	
	Equipment	Labor
11. Trench & backfill		
12. Cable		
13. Total		

14. Cost per distribution circuit $______

(b) Connection to Poles

Item	Cost per Foot (dollars)	
	Equipment	Labor
15. Trench & backfill		
16. Cable		
17. Total		

18. Cost of connection per circuit $______

19. Total distribution cost per circuit $______

Figure 8. Cost data form.

OMC I, Cont.

20. Control Equipment

Equipment Item	Initial Cost per Circuit (dollars)	
	Equipment	Labor
Time Controls:		
Photoelectric control and receptacle		
Time Switch		
Transformers:		
Constant-current		
Distribution		
Hanger irons		
Group Control:		
Protective relay		
Multiple relay		
Oil switch		
Multiple control switch		
Power-factor correcting capacitor		
Mounting bracket for capacitor		
Potential transformers		
Time-delay-lockout relay		
Fuse cutouts		
Other		
21. Total		

22. Total distribution and control cost per mile $________

23. Total initial cost per mile $________

24. Interest rate used ________%

25. Time period used ________yrs

26. Equivalent annual cost per mile $________

Figure 8. (Continued).

OMC I, Cont.

b. Maintenance and Power Costs

(1) Per Pole

Mainten-ance Item	Mainten-ance Fre-quency	Cost (dollars)			
		Equipment		Annual	Total
		Unit	Annual	Labor	Annua
27. Replace lamp					
28. Replace refractor					
29. Wash luminaire					
30. Total lamp and luminaire					
31. Replace ballast					
32. Paint pole					
33. Remove damaged pole					
34. Install new pole					
35. Total ballast and pole					

36. Total annual maintenance cost per pole, "per-pole" item $________

37. Total annual maintenance cost per mile, "per-pole" item $________

OMC I, Cont.

b. Maintenance and Power Costs, Cont.

(2) Per Circuit

38. Equipment

Type	Maintenance Cost Per Circuit Per Year (dollars)
Time Controls:	
Photoelectric control and receptacle	
Time switch	
Transformers:	
Distribution	
Hanger irons	
Group-Control:	
Protective relay	
Multiple relay	
Oil switch	
Multiple control switch	
Power-factor-correcting capacitor	
Potential transformer	
Time-delay-lockout relay	
Fuse cutouts	
Other	
39. Total	

40. Total annual control equipment cost per mile $__________
41. Total annual maintenance cost per mile $__________
42. Energy rate per kwh $__________
43. Kilowatts per mile $__________
44. Total annual energy cost per mile $__________
45. Total annual cost per mile $__________

OMC II: User Ownership, Utility Maintenance

46. Cost per lamp per year $__________
47. Total annual cost per mile $__________

OMC IIIA: Utility Ownership and Maintenance, Aggregate

48. Cost per lamp per year $__________
49. Added Costs $__________
50. Total annual cost per mile $__________

OMC IIIB: Utility Ownership and Maintenance, Detail

51. Cost per lamp per year $__________
52. Added costs $__________
53. Cost per pole per year $__________
54. Total cost per unit per year $__________
55. Total annual facility cost $__________
56. Total annual cost per mile $__________

Determination of Feasible Lighting Configurations

Feasible lighting configurations can be determined in three primary ways. (A feasible lighting configuration is one that provides the minimum desired illumination, *w*, shown as Item (10) in Form 1 (Fig. 4), and also provides a uniformity ratio(s) equal to or less than the desired ratio.) The three ways of determining feasible designs are: (1) through use of a formula that relates unit spacing to average illumination, (2) through use of empirically derived iso-footcandle overlays, and (3) through use of point-by-point calculations. After unit spacing that provides desired illumination is derived, the uniformity ratio is checked. If it is acceptable, the design is feasible. If it is not, the spacing is reduced until the ratio is acceptable, at which point the design is feasible.

For example, using the spacing formula, initial design and roadway conditions are specified; these include most items shown on Forms 1 and 2 (Figs. 4 and 5), as follows: lamp type and characteristics, luminaire mounting height, luminaire overhang, and luminaire. The required light distribution is determined and a luminaire arrangement is chosen. Then coefficient of utilization, the maintenance factor, and other correction factors are calculated or obtained. Then, spacing in feet, S, is determined using an appropriate formula to calculate spacing for a desired intensity or to calculate intensity for a given spacing. Next, the uniformity ratio is checked and, if not met, spacing is changed until it is met.

The foregoing steps are completed several times, generating feasible lighting configurations with different arrangements, spacings, mounting heights, lamp wattages, etc. Cols. 9, 10, and 11 of Form 2 (Fig. 5) and all of Form 3 (Fig. 6) are completed for each feasible configuration. It is important to consider several different configurations, so that "best" designs are considered in the cost-effectiveness comparisons.

Circuit Alternatives

After different feasible configurations have been determined, it is necessary to specify equipment and determine lighting circuits for each configuration.

Each alternative lighting configuration can have several different circuits; these different circuits are determined (see Cassel and Medville (*28*) for examples) and Parts a, c, and d of Form 4 (Fig. 7) are completed for each circuit.

Cost Calculations

Form 5 (Fig. 8) is completed for each circuit, and the costs are summarized in Part b of Form 4. By comparing the different circuits and their costs under different ownership arrangements, the designer chooses a preferred circuit and ownership arrangement and enters the number of this circuit in Col. 2 of Form 2 (Fig. 5) and enters the critical costs in maintenance and power costs in Cols. 3 and 5. By use of the analysis period and interest rate from Form 1 (Fig. 4), a uniform series capital recovery factor is obtained from a table and multiplied by initial costs in Col. 3 to obtain equivalent capital costs, which are entered in Col. 4. Cols. 4 and 5 are added to obtain Col. 6. Then, Col. 9 is divided by Col. 6 and the quotient is multiplied by the "multiplier" (Item 11 in Form 1) to obtain a priority index, which is entered in Col. 12.

It also is desirable to calculate expected accident costs for vehicles hitting lighting installations. The formula is

$$C_A = (\mathrm{ADT}/\mathrm{XDT})\ \mathrm{EA}\ C \qquad (6)$$

in which

C_A = the expected average accident cost from vehicles hitting lighting units, in dollars per mile per year;
ADT = the design average daily traffic (Item 7 in Form 1);
XDT = the number of vehicles of ADT that it takes to generate one out-of-control vehicle running off the road per mile per year (estimates are given in the footnote of Table 20);
EA = the expected numbers of lighting units per vehicle running off road (from Table 19 for the appropriate spacing and width of units from nearest traffic lane); and
C = the average cost of a vehicle-lighting unit accident, taken from the last column of Table 21 (or the sum of Cols. 3 and 4) if lighting pole damage has already been considered in maintenance costs).

The cost C_A is calculated for one mile of road and should be multiplied by the number of miles in the facility to get total annual lighting-unit accident cost, which is entered in Col. 7 of Form 2. Col. 7 is then added to Col. 6 to get Col. 8. The "multiplier" from Form 1 is multiplied by average footcandles from Col. 9 and divided by Col. 8 to get the priority index, which is entered in Col. 13.

By comparing the priority indices for different configurations in Cols. 12 and 13, the designer chooses one configuration he considers to be the "best." This configuration number, priority index, annual cost, average footcandles, and uniformity ratio(s) are entered in Cols. 15 through 19 of Form 1. This configuration, with its priority index(es), is used for this facility in over-all priority determinations. From a group of candidate facilities in a comprehensive lighting program, the facilities with the highest priority indices would be scheduled first for implementation.

TABLE 20

EXPECTED NUMBER OF LIGHTING POLE ACCIDENTS PER MILE OF ROADWAY PER YEAR, FOR EXPOSED ILLUMINATING UNITS [a]

UNIT SPACING (FT)	EXPECTED ACCIDENTS PER MILE WHEN UNITS ARE BACK FROM EDGE OF TRAFFIC LANE					
	0 FT	10 FT	15 FT	20 FT	25 FT	30 FT
100	1.31	1.18	1.03	0.85	0.59	0.33
150	0.88	0.79	0.70	0.57	0.40	0.22
200	0.66	0.59	0.52	0.43	0.30	0.17
250	0.53	0.48	0.42	0.34	0.24	0.13
300	0.44	0.40	0.35	0.29	0.20	0.11
350	0.38	0.34	0.30	0.25	0.17	0.10

[a] Expected accidents per mile per year: per 5,000 vehicles of two-way ADT for median or opposite arrangement; per 10,000 vehicles of two-way ADT for one-side and staggered arrangement; per 2,500 vehicles of two-way ADT for median-opposite arrangement.
Source: Based on McFarland and Walton (*29*, p. 17).

TABLE 21

AVERAGE ACCIDENT COSTS BY TYPE OF COST FOR DIFFERENT BASE AND POLE TYPES [a]

TYPE OF POLE	TYPE OF BASE	AVERAGE COST ($) INJURY	VEHICLE DAMAGE	LIGHTING INSTALLATION DAMAGE	TOTAL ACCIDENT
Aluminum	Aluminum transformer	174	381	221	776
Steel	Aluminum transformer	272	400	313	985
Steel	Steel transformer	603	501	231	1335
Steel	Steel shoe	823	541	103	1467

[a] These costs do not include cost of pain and suffering. Also, the costs used do not fully reflect the increasing severity of injuries (including death) associated with nonbreakaway bases (steel transformer, steel shoe). Therefore, injury costs for steel transformer and steel shoe bases probably are considerably larger than the values shown.

Source: McFarland and Walton (*29*, p. 24).

The priority index is of the model

$$P_x = \frac{E \frac{ADT_N}{n} L \frac{F}{W}}{C_A} \quad (7)$$

in which

P_x = Priority index;
E = Calculated lighting effectiveness (total warranting points);
ADT_N = Design night average daily traffic;
n = Number of lanes;
L = Affected lane-miles;
F = Actual design level of average intensity;
W = Warranted design level of average intensity; and
C_A = Annual costs.

As expressed in the preceding forms and discussion, this model is equivalent to

$$P_x = \frac{E\, ADT_N\, L}{W\, n} \frac{F}{C_A} \quad (8)$$

in which $\frac{E\, ADT_N\, L}{W\, n}$ is the multiplier of Col. 12 or 13, Form 2; F is the value in Col. 9, Form 2; and C_A is the value in Col. 6 or 8, Form 2.

The priority index is considered as a dimensionless term. However, dimensional analysis would indicate considerable rationale in the true dimensions, effective vehicle-miles per dollar cost.

CHAPTER THREE

INTERPRETATION, APPRAISAL, AND APPLICATION

INTERPRETATION AND APPRAISAL

The various tasks accomplished during the course of this study are discussed briefly in Chapter Two and in more detail in the appendices. A total design process, based on efficiency of night visual communications and traffic facility characteristics, has been developed. The comments that follow reflect the opinions of the research staff, based on their understanding of the present state-of-the-art and practice of highway lighting.

The comments are intended to serve as interpretation and appraisal of the information contained in this report. Immediate applications of the research findings are indicated and revisions to *An Informational Guide for Roadway Lighting* (*10*) are suggested.

1. A basic framework or concept is necessary for the development of a comprehensive lighting design process. A cursory review of the literature and the detailed state-of-the-art study in roadway lighting research and practice revealed that extremely complex relationships exist within the over-all design process for roadway lighting. Requirements, guidelines, warranting conditions, benefits, priorities, and cost-effectiveness are all interrelated to the extent that positive separation is difficult, if not impossible. It appeared necessary, therefore, for the total design process to be developed around one common framework or concept.

A conceptual framework was developed with this in mind. The most logical basis for the conceptual framework was determined to be the purpose of roadway lighting itself—improve the efficiency of night visual communications on traffic facilities. Night visual communications consist of providing the driver with the information he needs to safely and efficiently operate a motor vehicle. This information is, in effect, the requirements for a suitable visual environment for safe and efficient traffic operations. Provision of the information needs by fixed roadway lighting and the resulting comfort to the driver are the benefits derived.

As informational needs increase on a traffic facility so does the need for lighting. Therefore, warranting conditions are nothing more than informational needs. Informational needs are determined by geometric, operational, and environmental conditions, and are reflected in accident history. These conditions are the determinants used in establishing warranting conditions. Minimum warranting conditions represent those found on average facilities.

The extent to which any given traffic facility exceeds minimum warranting conditions becomes the priority determinant. Increasing informational needs reflect increasing warranting conditions, and as more and more people benefit from providing the needs the priority becomes greater.

Provision of needed information also serves as a measure of effectiveness. Optimum cost-effectiveness occurs when more needs are provided (effectiveness) to more people at equal cost. This optimal solution is the priority index.

2. There are three basic levels of performance in the driving task. King and Lunenfeld (*9*) developed a concept of the driving task based on communications. Empirical testing of the concept revealed that there are three basic levels of performance:

(a) Positional level—routine steering and/or speed adjustments necessary to maintain a desired speed and to remain within the lane.

(b) Situational level—change in speed, direction of travel, or position on the roadway, required as a result of the change in geometric, operational, and/or environmental situation.

(c) Navigational level—selecting and following a route from the origin to the destination of a trip.

These levels can be ordered into a hierarchy that describes the organizational content of the driving task. Performance at one level affects performance at the other levels. When high performance demands occur at any level, the driver cannot adequately attend to levels higher in the hierarchy, but must attend to those lower in the hierarchy. In an overloaded situation the driver will shed (load-shedding) all driving task levels higher, but not those lower.

3. There are informational needs associated with each level of performance in the driving task. In the current research effort, the diagnostic team approach was used to determine visual information needs at night. These needs were classified in accordance with the type of information involved (positional, situational, navigational). The classification revealed that most informational needs at night are associated with the situational level of performance, and in many cases it was the inadequacy of positional information that produced the situational needs. Adequate provision of positional information in the form of lane lines, edge lines, and curb delineation, is the most critical element of the environment because it holds the key to performance at other levels. If a driver is forced to search for positional information, little time is left to attend to the important situational and navigational tasks.

Although the field studies were limited in number, there is sufficient evidence that the major role of roadway lighting is to improve situational visual communications. The task is made easier if adequate positional information is present.

4. Geometric, operational, and environmental characteristics of a traffic facility determine the informational needs and, thus, the efficiency of night visual communications. The informational needs developed in this research were classified as to the conditions producing them. It was possible to classify most needs on the basis of geometric, operational, and environmental conditions. Those needs that could not be classified on this basis were classified simply as "general visibility." This usually resulted when a desired bit of information was totally absent rather than just a problem.

The geometric, operational, and environmental conditions delineated in the study were used as the parameters for traffic facility classification. The traffic facility classification was developed to be the manner in which a facility is evaluated for lighting needs and minimum warranting conditions. It was not possible to completely quantify the conditions from the results of the field study. A quantification of the conditions could have been attempted from the results, but it was believed that a better system would result through supplementing them with accident data from the literature and subjective judgment by a research team. The adequacy of the classification scheme is dependent on the reliability of the field studies, accident data in the literature, and professional judgment. The research staff is confident that at least a basic framework is established that can be used to structure the total lighting process.

5. Roadway lighting is warranted by the informational needs on a traffic facility. The classification process developed in this research is nothing more than a method of determining visual information needs on a given traffic facility, and, thus, justification (warrants) for lighting. Present guides for establishing warrants consist of traffic volumes, locational factors (suburban, urban, etc.), and accident history. The process developed in this research is a more definite quantification of traffic conditions, geometric conditions, locational conditions (environmental), and accident potential as well as accident history.

The minimum warranting conditions are those for average conditions on a given functional classification. There is room for debate as to the location of the minimum conditions on the scale. The ultimate answer as to the proper location depends on the basic philosophy chosen:

(a) Minimize sites warranting lighting—illumination is desirable on all roadways; but, due to the limitation of available funds, only a few sites should be warranted in order to have a firm basis for declining to light a section of roadway when requested to do so.

(b) Maximize sites warranting lighting—illumination is desirable on all roadways and available funds will be provided for illumination on relatively few. To encourage the allocation of funds to pay the costs, the warranting conditions should be very liberal.

The philosophy of this research has been "middle-of-the-road."

It may be desirable for those using the process developed herein to set their own minimum level. However, it is recognized that a line must be drawn somewhere if the warrants are to be administered on a national scope.

The true effect of setting the minimum conditions may not be as critical as it seems. If a priority procedure is followed in conjunction with the warrants, those facilities with greatest needs will be scheduled first for implementation and will receive the available funds.

6. The design level of lighting intensity is dependent on the magnitude of the informational needs on a given facility. A positive method for determining the design level of lighting intensity has been suggested in this research. It is proportional to warranting conditions and, thus, information needs. It is not directly related to any specific visual task problem. Ideally, a vision model would be developed such that every conceivable geometric, operational, and environmental modifier could be accounted for in any given visual task problem. It would also be ideal to have available pavement reflectance data for all pavement types and for the lighting designer to have control over pavement reflectance for the design life of the lighting system. Such a vision model is probably not practical or possible. Thus, in the absence of such a model, the procedure developed herein is a logical solution.

7. 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 and not all lighting effectiveness can be measured in dollar terms. What is the value of one informational input? Or, what is the value of driver comfort?

This research has suggested that effectiveness be measured in terms of supplying informational needs. As more needs are provided, the effectiveness of lighting increases.

The approach developed by Cassel and Medville (*28*), and modified in this research, provides a means of evaluating alternative designs on the basis of costs for equal effectiveness. A "best" design for a given lighting job may be selected and entered into priority competition.

8. Priorities for fixed lighting installations are established on the basis of need as related to cost. Total warranting points, which depend on magnitude of informational needs, serve as the effectiveness measure in priority determination. The priority model developed in the research is of the form

$$P_x = \frac{E \dfrac{ADT_N}{n} L \dfrac{F}{W}}{C_A} \quad (7)$$

in which

P_x = Priority index;
E = Calculated lighting effectiveness (total warranting points;
ADT_N = Design night average daily traffic;
n = Number of lanes;
L = Affected lane-miles;
F = Actual design level of average intensity;
W = Warranted design level of average intensity; and
C_A = Annual costs.

The priority model will favor those facilities with high warranting conditions that can be lighted most economically.

APPLICATION

The design process developed in this research can be used to administer a total lighting program. It provides a logical framework for lighting design, warranting conditions, and priority determination.

The information previously discussed can logically supplement *An Informational Guide for Roadway Lighting* (*10*) and the proposed *American National Standard Practice for Roadway Lighting* (*13*).

FORM 1

Identification Number: 1

SUMMARY

(1) Facility location: Dallas, Harry Hines Blvd.
(2) Facility type: Divided arterial
(3) Road length: 1 mile
(4) Road width(s): 72′
(5) Number of lanes (n): 4
(6) Affected lane-miles (L): 4
(7) Design average daily traffic: 32,000
(8) Design night average daily traffic (ADT_N): 8,000
(9) Warranted illumination level, ave. maintained footcandles (w): $\frac{86.3}{85} \times 1 = 1.0$
(10) Calculated lighting effectiveness or total warranting points (E): 86.3
(11) Multiplier = $(E \times ADT_N \times L)/(n \times w)$: 690,400
(12) Analysis period (years): 20
(13) Interest rate (%): 6
(14) Desired uniformity ratio(s): 3:1

Best Design

(15) Configuration number: 1
(16) Priority index(es): 202
(17) Annual cost: $4,100
(18) Ave. maintained footcandles: 1.2
(19) Uniformity ratio(s): 2.7:1

Figure 9. Summary form for identification number 1.

FORM 2

COST AND EFFECTIVENESS SUMMARY FORM

IDENTIFICATION NUMBER: 1

			ANNUAL COST[c]					EFFECTIVENESS				
											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	18,000	1,570	1,760	3,330	770	4,100	1.2	.45	2.7:1	248	202
2	1	25,000	2,180	2,500	4,680	1,080	5,760	1.3	.45	2.9:1	192	156
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 10. Cost and effectiveness summary form for identification number 1.

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A-B)	SCORE (RATING X(A-B))
GEOMETRIC FACTORS									
No. of lanes	4 or less	-	6	-	8 or more	1.0	0.8	0.2	0.2
Lane Width	>12'	12'	11'	10'	<10'	3.0	2.5	0.5	1.0
Median Openings per mile	<4.0 or one 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	8.0
Curb Cuts	<10%	10-20%	20-30%	30-40%	>40%	5.0	3.0	2.0	10.0
Curves	<3.0°	3.1-6.0°	6.1-8.0°	8.1-10.0°	>10°	13.0	5.0	8.0	8.0
Grades	<3%	3.0-3.9%	4.0-4.9%	5.0-6.9%	7% or more	3.2	2.8	0.4	0.4
Sight Distance	>700'	500-700'	300-500'	200-300'	<200'	2.0	1.8	0.2	0.2
Parking	prohibited both sides	loading zones only	off-peak only	permitted one side	permitted both sides	0.2	0.1	0.1	0.1
						GEOMETRIC TOTAL			27.9
OPERATIONAL FACTORS									
Signals	all major intersections signalized	substantial majority of intersections signalized	most major intersections signalized	about half the intersections signalized	frequent non-signalized intersections	3.0	2.8	0.2	0.8
Left turn lane	all major intersections or one way operation	substantial majority of intersections	most major intersections	about half the major intersections	infrequent turn bays or undivided streets	5.0	4.0	1.0	4.0
Median Width	30'	20-30'	10-20'	4-10'	0-4'	1.0	0.5	0.5	1.0
Operating Speed	25 or less	30	35	40	45 or greater	1.0	0.2	0.8	4.0
Pedestrian Traffic at night (peds/mi)	very few or none	0-50	50-100	100-200	>200	1.5	0.5	1.0	3.0
						OPERATIONAL TOTAL			11.8
ENVIRONMENTAL FACTORS									
% Development	0	0-30%	30-60%	60-90%	100%	0.5	0.3	0.2	1.0
Predominant Type Development	undeveloped or backup design	residential	half-residential and/or commercial	industrial or commercial	strip industrial or commercial	0.5	0.3	0.2	1.0
Setback Distance	>200	150-200'	100-150'	50-100'	<50	0.5	0.3	0.2	0.6
Advertising or area lighting	none	0-40%	40-60%	60-80%	essentially continuous	3.0	1.0	2.0	10.0
Raised Curb Median	none	continuous	at all intersections	at signalized intersections	a few locations	1.0	0.5	0.5	1.0
Crime Rate	extremely low	lower than city aver.	city aver.	higher than city aver.	extremely high	1.0	0.5	0.5	1.0
						ENVIRONMENTAL TOTAL			14.6
ACCIDENTS									
Ratio of night to day accident rates	<1.0	1.0-1.2	1.2-1.5	1.5-2.0	2.0*	10.0	2.0	8.0	32.0
						ACCIDENT TOTAL			32.0

*Continuous lighting warranted

GEOMETRIC TOTAL = 27.9
OPERATIONAL TOTAL = 11.8
ENVIRONMENTAL TOTAL = 14.6
ACCIDENT TOTAL = 32.0
SUM = 86.3 POINTS
WARRANTING CONDITION = 85 points

Figure 11. Example 1: Classification for noncontrolled-access facility lighting.

Typical Examples

The final objective specified in the project statement for the subject research reads:

> Provide typical example(s) of where lighting is warranted and demonstrate the practical application of objectives one through six.

This section is in response to this objective.

Three sections from the Dallas study sites (described in Appendix B) have been chosen as examples. They are:

1. Section 1 under "Unlighted Arterials," designated as Identification No. 1.
2. Section 3 under "Unlighted Arterials," designated as Identification No. 2.
3. Section 3 under "Unlighted Freeways," designated as Identification No. 3.

Traffic facility classification forms have been prepared for the three sections. (Some of the geometric, operational, and environmental data have been estimated for the purposes of these examples. All accident ratios also have been estimated.) These forms reveal that each of the three sections warrants fixed lighting.

Section 1 of the unlighted arterials (Ident. No. 1) received total warranting points of 86.3 (Figs. 9, 10, and 11). This provides for a design lighting level of approximately 1.0 hor. ft-cd (pavements were assumed to be average in reflectance).

Section 3 of the unlighted arterials (Ident. No. 2) received total warranting points of 117.3 (Figs. 12, 13, and 14). This provides a design lighting level of 1.4 hor. ft-cd.

Section 3 of the unlighted freeways (Ident. No. 3) received total warranting points of 112.3 (Figs. 15, 16, and 17). This provides a design lighting level of approximately 0.7 hor. ft-cd.

Forms 1 and 2, discussed in Chapter Two under "Warrants and Priorities" and "Cost-Effectiveness," have been prepared for each of the three sections. Form 1 is the summary form for each section and is self-explanatory. Form 2 is the cost and effectiveness summary form for each section. Details for completing the data in Form 2 are provided by Forms 3, 4, and 5 (Figs. 6, 7, and 8), discussed previously. These forms have not been completed for the examples given here.

The cost and effectiveness summary forms (Form 2) indicate the priority index for each section. The highest or "best" priority index from either Col. 12 or Col. 13 is selected, depending on whether or not it is desired to include costs associated with vehicle-pole accidents. It is highly recommended that these costs be included in the analysis.

For the examples illustrated, priority indices of 202, 240,

FORM 1

Identification Number: 2

SUMMARY

(1) Facility location: Dallas, Loop 12 (Northwest Hwy.)
(2) Facility type: Undivided arterial
(3) Road length: 1 mile
(4) Road width(s): 44′
(5) Number of lanes (n): 4
(6) Affected lane-miles (L): 4
(7) Design average daily traffic: 36,000
(8) Design night average daily traffic (ADT_N): 9,000
(9) Warranted illumination level, ave. maintained foot-candles (w): $\frac{117.3}{85} \times 1.0 = 1.4$
(10) Calculated lighting effectiveness or total warranting points (E): 117.3
(11) Multiplier $= (E \times ADT_N \times L)/(n \times w)$: 754,071
(12) Analysis period (years): 20
(13) Interest rate (%): 6
(14) Desired uniformity ratio(s): 3:1

Best Design

(15) Configuration number: 1
(16) Priority index(es): 240
(17) Annual cost: $4,710
(18) Ave. maintained footcandles: 1.5
(19) Uniformity ratio(s): 3:1

Figure 12. Summary form for identification number 2.

FORM 1

Identification Number: 3

SUMMARY

(1) Facility location: Dallas, Stemmons Expressway (IH35)
(2) Facility type: Freeway
(3) Road length: 1 mile
(4) Road width(s): 108′
(5) Number of lanes (n): 8
(6) Affected lane-miles (L): 8
(7) Design average daily traffic: 80,000
(8) Design night average daily traffic (ADT_N): 20,000
(9) Warranted illumination level, ave. maintained foot-candles (w): $\frac{112.3}{95} \times 0.6 = 0.7$
(10) Calculated lighting effectiveness or total warranting points (E): 112.3
(11) Multiplier $= (E \times ADT_N \times L)/(n \times w)$: 3,208,571
(12) Analysis period (years): 20
(13) Interest rate (%): 6
(14) Desired uniformity ratio(s): 3:1

Best Design

(15) Configuration number: 1
(16) Priority index(es): 238
(17) Annual cost: 9420
(18) Ave. maintained footcandles: 0.7
(19) Uniformity ratio(s): 3:1

Figure 15. Summary form for identification number 3.

FORM 2

COST AND EFFECTIVENESS SUMMARY FORM

IDENTIFICATION NUMBER: 2

			ANNUAL COST[c]					EFFECTIVENESS				
											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	1	23,000	2,010	1,750	3,760	950	4,710	1.5	.5	3:1	301	240
2	1	24,000	2,090	2,180	4,270	950	5,220	1.4	.5	2.8:1	247	202
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 13. Cost and effectiveness summary form for identification number 2.

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A-B)	SCORE [RATING X(A-B)]
GEOMETRIC FACTORS									
No. of lanes	4 or less	-	6	-	8 or more	1.0	0.8	0.2	0.2
Lane Width	>12'	12'	11'	10'	<10'	3.0	2.5	0.5	1.5
Median Openings per mile	<4.0 or one 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	10.0
Curb Cuts	<10%	10-20%	20-30%	30-40%	>40%	5.0	3.0	2.0	8.0
Curves	<3.0°	3.1-6.0°	6.1-8.0°	8.1-10.0°	>10°	13.0	5.0	8.0	40.0
Grades	<3%	3.0-3.9%	4.0-4.9%	5.0-6.9%	7% or more	3.2	2.8	0.4	2.0
Sight Distance	>700'	500-700'	300-500'	200-300'	<200'	2.0	1.8	0.2	0.8
Parking	prohibited both sides	loading zones only	off-peak only	permitted one side	permitted both sides	0.2	0.1	0.1	0.1
						GEOMETRIC TOTAL			62.6
OPERATIONAL FACTORS									
Signals	all major intersections signalized	substantial majority of intersections signalized	most major intersections signalized	about half the intersections signalized	frequent non-signalized intersections	3.0	2.8	0.2	0.2
Left turn lane	all major intersections or one way operation	substantial majority of intersections	most major intersections	about half the major intersections	infrequent turn bays or undivided streets	5.0	4.0	1.0	5.0
Median Width	30'	20-30'	10-20'	4-10'	0-4'	1.0	0.5	0.5	2.5
Operating Speed	25 or less	30	35	40	45 or greater	1.0	0.2	0.8	4.0
Pedestrian Traffic at night (peds/mi)	very few or none	0-50	50-100	100-200	>200	1.5	0.5	1.0	5.0
						OPERATIONAL TOTAL			16.7
ENVIRONMENTAL FACTORS									
% Development	0	0-30%	30-60%	60-90%	100%	0.5	0.3	0.2	1.0
Predominant Type Development	undeveloped or backup design	residential	half-residential and/or commercial	industrial or commercial	strip industrial or commercial	0.5	0.3	0.2	1.0
Setback Distance	>200	150-200'	100-150'	50-100'	<50	0.5	0.3	0.2	1.0
Advertising or area lighting	none	0-40%	40-60%	60-80%	essentially continuous	3.0	1.0	2.0	10.0
Raised Curb Median	none	continuous	at all intersections	at signalized intersections	a few locations	1.0	0.5	0.5	0.5
Crime Rate	extremely low	lower than city aver.	city aver.	higher than city aver.	extremely high	1.0	0.5	0.5	0.5
						ENVIRONMENTAL TOTAL			14.0
ACCIDENTS									
Ratio of night to day accident rates	<1.0	1.0-1.2	1.2-1.5	1.5-2.0	2.0*	10.0	2.0	8.0	24.0
						ACCIDENT TOTAL			24.0

*Continuous lighting warranted

GEOMETRIC TOTAL = 62.6
OPERATIONAL TOTAL = 16.7
ENVIRONMENTAL TOTAL = 14.0
ACCIDENT TOTAL = 24.0
SUM = 117.3 POINTS
WARRANTING CONDITION = 85 points

Figure 14. Example 2: Classification for noncontrolled-access facility lighting.

FORM 2

COST AND EFFECTIVENESS SUMMARY FORM

IDENTIFICATION NUMBER: 3

			ANNUAL COST[c]					EFFECTIVENESS				
											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	1	46,000	4,020	3,500	7,520	1,900	9,420	0.7	.23	3:1	299	238
2	3	39,000	3,400	3,990	7,390	2,170	9,560	0.7	.25	2.8:1	303	235
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 16. Cost and effectiveness summary form for identification number 3.

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A-B)	SCORE [RATING X(A-B)]
GEOMETRIC FACTORS									
No. of Lanes	4		6		≥8	1.0	0.8	0.2	1.0
Lane Width	>12'	12'	11'	10'	≤9'	3.0	2.5	0.5	1.0
Median Width	>40'	24-39'	12-23'	4-11'	0-3'	1.0	0.5	0.5	2.0
Shoulders	10'	8'	6'	4'	0'	1.0	0.5	0.5	1.5
Slopes	≥8:1	6:1	4:1	3:1	2:1	1.0	0.5	0.5	2.0
Curves	0-1/2°	1/2-1°	1-2°	2-3°	3-4°	13.0	5.0	8.0	32.0
Grades	<3%	3-3.9%	4-4.9%	5-6.9%	>7%	3.2	2.8	0.4	0.8
Interchange Freq.	4 mi.	3 mi.	2 mi.	1 mi.	<1 mi.	4.0	1.0	3.0	15.0
						GEOMETRIC TOTAL			55.3
OPERATIONAL FACTORS									
Level of Service (any dark hour)	A	B	C	D	E	6.0	1.0	5.0	15.0
						OPERATIONAL TOTAL			15.0
ENVIRONMENTAL FACTORS									
% Development	0%	25%	50%	75%	100%	3.5	0.5	3.0	12.0
Offset to Develop	200'	150'	100'	50'	<50'	3.5	0.5	3.0	6.0
						ENVIRONMENTAL TOTAL			18.0
ACCIDENTS									
Ratio of night to day accident rates	1.0	1-1.2	1.2-1.5	1.5-2.0	2.0*	10.0	2.0	8.0	24.0
						ACCIDENT TOTAL			24.0

*Continuous lighting warranted

GEOMETRIC TOTAL = 55.3
OPERATIONAL TOTAL = 15.0
ENVIRONMENTAL TOTAL = 18.0
ACCIDENT TOTAL = 24.0
SUM = 112.3 POINTS
WARRANTING CONDITION = 95 points

Figure 17. Example 3: Classification for controlled-access facility (freeway) lighting.

and 238 are selected from Form 2. These are shown on Form 1 and indicate the following priorities for fund expenditures:

1. Section 3, unlighted arterials; Identification No. 2.
2. Section 3, unlighted freeways; Identification No. 3.
3. Section 1, unlighted arterials; Identification No. 1.

It should be noted that the actual values shown for the three sections are representative only and not exact.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

The procedures developed during this study should be used to develop a total lighting design process. A revision of *An Informational Guide for Roadway Lighting* (*10*) should be prepared on the basis of current knowledge from the research and practice. It is recognized that setting policies and procedures for administration purposes is not within the province of research. However, it is believed that the current design guidelines and warrants should be rewritten.

It is concluded that the rational design approach outlined in this report is a usable technique, and that the procedures involved provide an insight into the interrelationships existing in the total lighting design problem. The approach should be evaluated closely by agencies responsible for its use and administration, and the results should be furnished to lighting engineers to aid them in their responsibilities.

Specific research tasks suggested for evaluation of the approach are as follows:

1. Preparation of an implementation procedure. It is recommended that an implementation procedure be developed outlining the function and details of the total design process. This procedure should be styled after the basic format of *An Informational Guide for Roadway Lighting* (*10*). The function of the procedure would be to field evaluate the approach.

2. Field evaluation of the approach. Several states and municipalities should be selected to implement the approach on a limited basis. Close evaluation of the approach would be made by the selected agencies and the results would be incorporated in the final revision of the *Informational Guide.*

3. Revision of An Informational Guide for Roadway Lighting. It is recommended that, after a trial implementation period of approximately one year, the basic approach be revised as appropriate to reflect the input of the agencies involved. The approach should then be presented as a revision of the *Informational Guide,* presenting details of the approach and implementation.

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APPENDIX A

STATE-OF-THE-ART QUESTIONNAIRE SURVEYS

QUESTIONNAIRE DEVELOPMENT AND OBJECTIVES

As part of the state-of-the-art study, questionnaires were constructed to provide information on current warrants, guidelines, and practices of roadway lighting. It was believed that information concerning the prevailing attitudes of state highway engineers, municipal public works departments, and other recognized experts in the field of roadway lighting toward current AASHTO guidelines would also be beneficial. With information gained from the questionnaires, the project staff hoped to more easily pinpoint weaknesses, if any, in the current published version of AASHTO guidelines. Therefore, the questionnaires were submitted to practicing highway engineers and other job-related personnel, as these professionals would be familiar with, as well as knowledgeable of, these guidelines.

Thirty-three statements concerning the various empirical guidelines provided by AASHTO were selected at random from AASHTO's *An Informational Guide for Roadway Lighting*. These statements covered warranting conditions and design values for (a) freeways, (b) highways other than freeways, (c) tunnels and underpasses, and (d) interchanges and intersections of freeways and other highways. A scale of possible responses for each statement ranged from "strongly agree," through "agree," "undecided," and "disagree," to "strongly disagree." Each respondent was to check one of these responses to indicate his attitude toward the statement. Scores of 5, 4, 3, 2, and 1 were assigned to each of the response categories, respectively.

QUESTIONNAIRE FORMS

State Highway Departments

As previously stated, the first 31 "questions" were actually statements selected at random from the AASHTO *Guide for Roadway Lighting*. These items on which the response scores were based, and which were common to all three basic questionnaires, as explained later, were as follows:

1. Supplemental lighting is really not necessary for underpasses under 75 ft in length, with respect to traffic operations.

2. If traffic volume is the only consideration, continuous freeway lighting is only justified for sections of free-

way in urban and suburban areas where the average daily traffic (ADT) count is 60,000 or greater.

3. The application of transitional lighting in freeway lighting situations will enhance driver comfort and expedite traffic operations.

4. Continuous freeway lighting is desirable if local streets adjacent to the freeway are lighted, and are visible from the freeway.

5. One case where a continuous freeway lighting system is justified occurs where the width of the roadway is restricted for some significant reason.

6. Continuous freeway lighting is necessary when the freeway passes through residential, commercial, or industrial areas that are lighted.

7. Rural intersections with raised channelizing or divisional islands may require a greater illumination level than what is normally applicable.

8. In urban areas where several successive interchanges are in close proximity to one another, it is desirable to incorporate a continuous freeway lighting system.

9. Short underpasses can be adequately lighted from luminaires positioned outside the underpasses.

10. When cross streets, some of which are lighted, intersect with a freeway at relatively short intervals, the freeway should be lighted continuously.

11. Where crossroad approaches are lighted, the crossroad through traffic lanes should also be lighted at approximately the same level.

12. Street lighting in general will contribute substantially to the efficiency, safety, and comfort of vehicular and pedestrian traffic in urban areas.

13. Consideration should be given to reducing the effects of sudden light change on drivers as they enter and exit a partially lighted interchange.

14. The lighting of an interchange is justified when lights from commercial or industrial developments create visibility problems for drivers on the interchange.

15. One justification for lighting long bridges should be aesthetic appeal.

16. Tunnels within the range of 100 to 500 ft should have two levels of illumination (i.e., night and day).

17. Lighting may be necessary where resulting benefits, both tangible and intangible, are in the interest of the general public or local governmental agencies.

18. The level of illumination for ramps where complete interchange lighting is provided should correspond to the illumination level for freeway through traffic.

19. Bridges and overpasses should be lighted at the same level of illumination and uniformity ratio as other roadway areas adjoining the bridge.

20. The level of illumination for continuous freeway lighting conditions should not be less than 0.6 footcandles average.

21. When raised channelizing or divisional islands are located at the intersections of ramp terminals with a crossroad, partial interchange lighting is justified.

22. It is desirable to minimize variation in the level of illumination or in the uniformity ratio on a continuously lighted freeway.

23. For continuous freeway lighting installations, the average-to-minimum uniformity of illumination ratio should approach 3:1.

24. The task of partial interchange lighting should be to illuminate the through traffic lanes and speed change lanes at diverging and merging locations.

25. Continuous freeway lighting is justified where, for a length of two or more miles, the freeway passes through a highly developed urban or suburban area.

26. Lighting should be provided for major arterials in urbanized areas, where the night-to-day accident ratio is high.

27. At locations where unusual weather conditions exist (i.e., abnormal amounts of fog, ice, or snow) lighting should be installed for the purpose of alleviating potential traffic problems.

28. From the perspective of traffic operations, there is little if any advantage to providing fixed-source lighting on long bridges, even though the approaches are unlighted.

29. Continuous freeway sections with a high night-to-day accident ratio should be lighted.

30. One instance where an interchange should be lighted is when the crossroads of that interchange are lighted for ½ mile or more on either side.

31. Three levels of illumination are required for long tunnels:

(a) One for daytime entrance zones.
(b) One for daytime interior zones.
(c) One for night.

(The 33 statements previously mentioned are contained in the 31 items listed, as item 31 is a three-part statement.)

The remaining items (32 through 56), designed to elicit information concerning guidelines and practices of roadway lighting currently used by the state highway departments, were as follows:

32. Do you use the same warrants for non-federally funded projects as you do for federally funded projects involving:

(a) The installation of continuous lighting systems?
__Yes __No
If no, how do they differ?

(b) The installation of safety lighting systems?
__Yes __No
If no, how do they differ?

(c) The installation of intersectional lighting systems?
__Yes __No
If no, how do they differ?

If the warrants are different, and second copies are available, please enclose a copy with the return.

33. Do you give any consideration to roadway geometry, environmental conditions, or traffic conditions beyond the scope of AASHTO warrants?
__Yes __No
If yes, to what extent and under what circumstances?

The following questions pertain to the procedure used for establishing a lighting design once lighting is found to be warranted. In answering the questions, please show the origin of information used in your answers. If this information is not available in a widely distributed publication, please furnish a copy.

34. For each category of roadway shown below, what is the average, minimum, and maximum intensity in terms of horizontal footcandles that you use in establishing a design?

	CONTINUOUS FREEWAYS			CONTINUOUS ARTERIALS		FREEWAY INTERCHANGES			ARTERIAL INTERCHANGES	
	URBAN	SUB-URBAN	RURAL	URBAN	SUB-URBAN	URBAN	SUB-URBAN	RURAL	URBAN	SUB-URBAN
AVERAGE INTENSITY										
MAXIMUM INTENSITY										
MINIMUM INTENSITY										

Origin of information used:

35. Is there a particular level of pavement brightness that you specify?

__Yes __No

What is this level in foot-lamberts for the following?

(a) Freeways: Urban_____ Suburban_____ Rural_____
(b) Arterials: Urban_____ Suburban_____
(c) Freeway interchanges: Urban_____ Suburban_____ Rural_____
(d) Arterial interchanges or intersections: Urban_____ Suburban_____

36. In any of your lighting designs, do you specify a maximum disability glare permitted at driver's eye level?

__Yes __No

If yes, what is the maximum value in foot-lamberts?

37. What factors determine the mounting height used in your most recent lighting installations? Do these factors differ with the class of roadway?

__Yes __No

If yes, how?

38. How is the spacing between luminaire supports determined?

39. (a) What determines the geometric configuration of luminaire supports; i.e., median, staggered, opposite, etc.?

(b) Which of the following geometric configurations do you prefer to use and why?

Median mounted
Staggered mounted
Opposite mounted
One side

(c) When do you use:

Median
Staggered
Opposite
One side

40. For the roadway types listed, what type of lamp and power in watts would you specify? (Example: 1,000-watt clear mercury vapor)

Continuous freeways
Continuous arterials
Full interchange lighting
Safety lighting

41. What is the highest mounting height you have used for the following categories?

	400-WATT	700-WATT	1,000-WATT
Continuous freeways	_____	_____	_____
Continuous arterials	_____	_____	_____
Full interchange lighting	_____	_____	_____
Safety lighting	_____	_____	_____

42. What mounting height do you normally use?

	400-WATT	700-WATT	1,000-WATT
Continuous freeways	_____	_____	_____
Continuous arterials	_____	_____	_____
Full interchange lighting	_____	_____	_____
Safety lighting	_____	_____	_____

43. If you anticipate using higher heights, indicate these heights.

	400 WATT	700-WATT	1,000-WATT
Continuous freeways	_____	_____	_____
Continuous arterials	_____	_____	_____
Full interchange lighting	_____	_____	_____
Safety lighting	_____	_____	_____

44. What line voltage do you normally specify in your installations? _____volts. Do the electric utilities assist in this specification?

__Yes __No

If yes, to what degree?

The following questions pertain to your normal maintenance and operation of lighting installations.

45. At what time intervals are cleaning and relamping performed on the following types of lighting installations?

Continuous freeway _____months
Continuous arterial _____months
Full interchange lighting _____months
Safety lighting _____months

46. Do you perform all of your own maintenance work on lighting installations?

__Yes __No

If no, who does it for you, and what portion?

47. Are you experiencing any difficulty with regard to maintenance of a particular type of mounting or mounting height?

__Yes __No

If yes, indicate the problem.

48. Are you experiencing any difficulty with a specific lamp type?

__Yes __No

If yes, indicate what type and the difficulty.

49. What ADT counts would you like to use in determining when to install continuous freeway lighting for the following areas?

Urban
Suburban
Rural

50. What ADT ramp traffic counts would you like to use in determining when to completely light an interchange for the following areas?

Urban
Suburban
Rural

51. What ADT through traffic counts would you like to use in determining when to install partial interchange lighting for the following areas?

Urban
Suburban
Rural

52. What ADT ramp traffic counts would you like to use in determining when to partially light an interchange in the following areas?

Urban
Suburban
Rural

53. Following is a list of various types of luminaire support bases in use today. If you use the base, check the space to the left of it, and also check the appropriate box to the right indicating where you use it.

	HIGH SPEED	LOW SPEED
(a)__Steel flange base,		
with guardrail protection	_____	_____
exposed	_____	_____
(b)__Aluminum flange base,		
with guardrail protection	_____	_____
exposed	_____	_____
(c)__Steel transformer base,		
with guardrail protection	_____	_____
exposed	_____	_____
(d)__Aluminum transformer base,		
with guardrail protection	_____	_____
exposed	_____	_____
(e)__Progressive shear base,		
with guardrail protection	_____	_____
exposed	_____	_____
(f)__Slip base,		
with guardrail protection	_____	_____
exposed	_____	_____

54. Your name (optional):

55. Name and address of State Highway Department:

56. Would you or one of your representatives be willing to discuss further your lighting practices with representatives of Texas Transportation Institute, Texas A&M University?

__Yes __No

If yes, is there a convenient date(s) between now and September 15?

Municipal Public Works Departments

For the questionnaire to municipal public works departments, the first 31 items were the same as for the questionnaire to the state highway departments. The remaining items (32 through 52), designed to elicit information concerning guidelines and practices of roadway lighting currently used by municipal public works departments, were as follows:

32. Do you give any consideration to roadway geometry, environmental conditions, or traffic conditions in establishing lighting needs?

__Yes __No

If yes, to what extent and under what circumstances?

The following questions pertain to the procedure used for establishing a lighting design once lighting is found to be warranted. In answering the questions, please show the origin of information used in your answers. If this information is not available in a widely distributed publication, please furnish a copy.

33. For each category of roadway shown below, what is the average, minimum, and maximum intensity in terms of horizontal footcandles that you use in establishing a design?

	FREEWAYS & EXPRESSWAYS		ARTERIALS		COLLECTORS		LOCALS		INTERCHANGES & INTERSECTIONS	
	URBAN	SUBURBAN	URBAN	SUBURBAN	URBAN	SUBURBAN	URBAN	SUBURBAN	URBAN	SUBURBAN
AVERAGE INTENSITY										
MAXIMUM INTENSITY										
MINIMUM INTENSITY										

Origin of information used:

34. Is there a particular level of pavement brightness that you specify?

__Yes __No

What is this level in foot-lamberts for the following?

(a) Freeways and expressways: Urban_____ Suburban_____
(b) Arterials: Urban_____ Suburban_____
(c) Collectors and locals: Urban_____ Suburban_____
(d) Freeway interchanges: Urban_____ Suburban_____
(e) Arterial interchanges or intersections: Urban_____ Suburban_____

35. In any of your lighting designs, do you specify a maximum disability glare permitted at driver's eye level?

__Yes __No

If yes, what is the maximum value in foot-lamberts?

36. What factors determine the mounting height used in your most recent lighting installations? Do these factors differ with the class of roadway?

__Yes __No

If yes, how?

37. How is the spacing between luminaire supports determined?

38. (a) What determines the geometric configuration of luminaire supports; i.e., median, staggered, opposite, etc.?

(b) Which of the following geometric configurations do you prefer to use and why?

Median mounted
Staggered mounted
Opposite mounted
One side

(c) When do you use:

Median
Staggered
Opposite
One side

39. For the roadway types listed what type of lamp and power in watts would you specify? (Example: 1,000-watt clear mercury vapor)

Freeways and expressways
Arterials
Collectors and locals
Interchange and intersection

40. What is the highest mounting height you have used for the following categories?

	400-WATT	700-WATT	1,000-WATT
Freeways and expressways	_____	_____	_____
Arterials	_____	_____	_____
Collectors and locals	_____	_____	_____
Interchange and intersection	_____	_____	_____

41. What mounting height do you normally use?

	400-WATT	700-WATT	1,000-WATT
Freeways and expressways	_____	_____	_____
Arterials	_____	_____	_____
Collectors and locals	_____	_____	_____
Interchange and intersection	_____	_____	_____

42. If you anticipate using higher heights, indicate these heights.

	400-WATT	700-WATT	1,000-WATT
Freeways and expressways	_____	_____	_____
Arterials	_____	_____	_____
Collectors and locals	_____	_____	_____
Interchange and intersection	_____	_____	_____

43. What line voltage do you normally specify in your installations? ____volts. Do the electric utilities assist in this specification?

__Yes __No

If yes, to what degree?

The following questions pertain to your normal maintenance and operation of lighting installations.

44. At what time intervals are cleaning and relamping performed on the following types of lighting installations?

Freeways and expressways _____months
Arterials _____months
Collectors and locals _____months
Interchanges and intersections _____months

45. Do you perform all of your own maintenance work on lighting installations?

__Yes __No

If no, who does it for you, and what portion?

46. Are you experiencing any difficulty with regard to maintenance of a particular type of mounting or mounting height?

__Yes __No

If yes, indicate the problem:

47. Are you experiencing any difficulty with a specific lamp type?

__Yes __No

If yes, indicate what type and the difficulty.

48. What traffic volumes (if applicable) do you use in determining when to light for the following roadway categories.

	URBAN	SUBURBAN
Freeways and expressways	______	______
Arterials	______	______
Collectors	______	______
Locals	______	______
Interchanges	______	______
Intersections	______	______

49. Following is a list of various types of luminaire support bases in use today. If you use the base, check the space to the left of it, and also check the appropriate box to the right indicating where you use it.

	HIGH SPEED	LOW SPEED
(a)__Steel flange base,		
with guardrail protection	____	____
exposed	____	____
(b)__Aluminum flange base,		
with guardrail protection	____	____
exposed	____	____
(c)__Steel transformer base,		
with guardrail protection	____	____
exposed	____	____
(d)__Aluminum transformer base,		
with guardrail protection	____	____
exposed	____	____
(e)__Progressive shear base,		
with guardrail protection	____	____
exposed	____	____
(f)__Slip base,		
with guardrail protection	____	____
exposed	____	____
(g)__Other,		
with guardrail protection	____	____
exposed	____	____

50. Your name (optional):

51. Name and address of municipalities you represent:

52. Would you or one of your representatives be willing to discuss further your lighting practices with representatives of Texas Transportation Institute, Texas A&M University?

__Yes __No

If yes, is there a convenient date(s) between now and October 1?

Individual Experts

The questionnaire to individual experts consisted only of the first 31 items used for both the state highway department and the municipal public works department versions. No further questions were included, as the type of information sought would not be applicable to this group of respondees.

QUESTIONNAIRE SURVEY RESULTS

General

Questionnaires of the proper make-up were sent, respectively, to the 50 state highway departments, 50 cities, and 25 individuals. Each respondent was assigned a score that was determined by summing the individual item scores (for the 33 common statement responses). This total score was then used as an indication of a respondent's attitude toward the AASHTO guidelines. If a respondent strongly agreed with all 33 statements, his total score was 165. Likewise, if he agreed, 132; was undecided, 99; disagreed, 69; or strongly disagreed, 33. A frequency distribution of these total scores is shown in Figure A-1. The results indicated that 78 out of 90 respondents are in agreement with the AASHTO guidelines; however, this did not imply that there is no significant *specific* disagreement with the AASHTO guidelines.

Of the 125 questionnaires sent out, 90 were returned. A nonparametric analysis of variance for differences in total scores for the three categories of respondents was attempted, but was invalidated by the large number of tie scores in the data. However, it did not appear that the average total response score differed significantly for the three groups (Table A-1). The average total score for all respondents was 128.348, within the range of the "agree" category. In fact, average scores for all categories fell within this range.

An analysis of the questionnaire statements according to topic categories is presented in the following. Statements referring to freeways are discussed first, interchanges second, highways other than freeways third, and underpasses, overpasses, tunnels, and bridges last. The questions and statement scores for each category of respondent are presented in Table A-2. The mean response and variance for each category of respondent are also reported in Table B-2 on a statement-by-statement basis.

Warrants

Freeways

Given a choice of two degrees of positive response (agree and strongly agree), a plurality of respondents chose "agree" rather than "strongly agree" for seven of the eleven statements related to the lighting of freeways. These seven statements included items 4, 5, 6, 10, 23, 25, and 29. This indicates an apparent unwillingness on the part of the respondents to strongly agree with the AASHTO guidelines as they pertain to freeway lighting installations. Statements 4 and 10 dealt with the lighting of streets adjacent to, or intersecting with, the freeway. Statements 6 and 25 were concerned with the lighting of a freeway that passes through highly developed property adjacent to the freeway. Three of the statements (2, 23, 29) dealt with various design values contained in the AASHTO guidelines. A surprising finding with regard to the average-to-minimum maintained

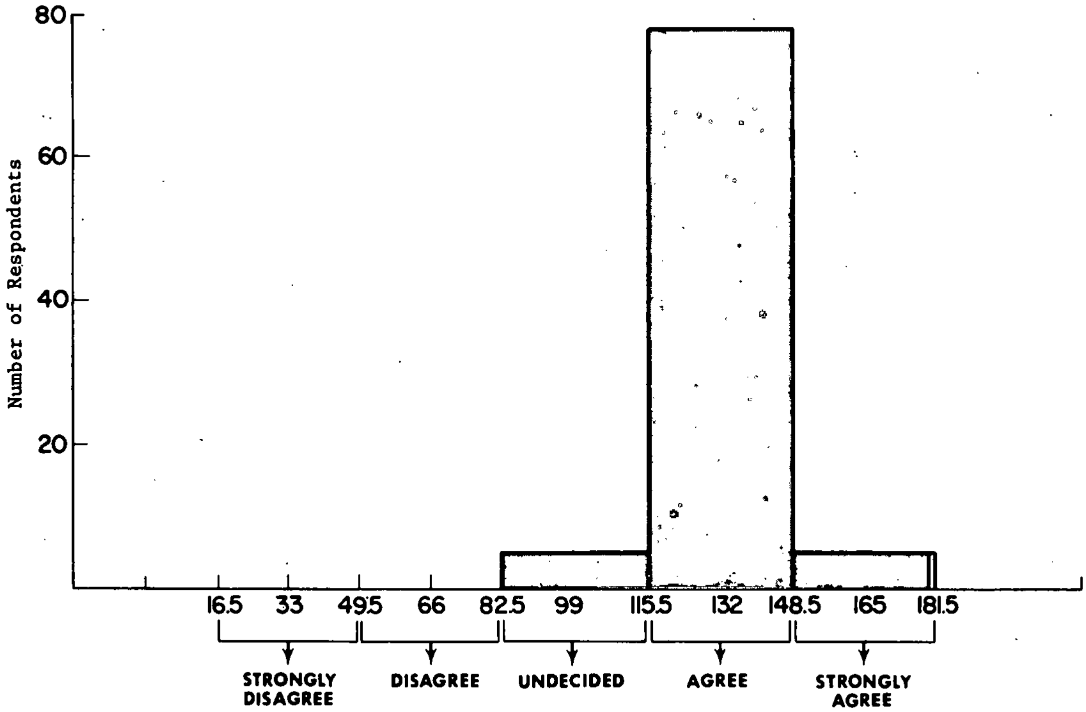


Figure A-1. Frequency distribution of questionnaire responses to the 33 basic statements.

uniformity ratio (item 23) was that 6 out of 90 respondents were in disagreement with this ratio, 10 were undecided, 44 agreed, and only 28 strongly agreed. This appears to be an indication that practicing engineers do not consider this uniformity ratio to be correct. The ADT count recommended by AASHTO was disagreed with almost entirely. Thirty-eight out of 90 respondents disagreed with this value, and 9 strongly disagreed. Another interesting finding with regard to design values was related to item 29. Only 29 out of 90 respondents strongly agreed with the statement that lighting is warranted when night-to-day accident ratios are high, and 49 others agreed. Although an obvious majority of the respondents answered positively to this statement, it is interesting that comparatively few strongly agreed with it. Two clearly positive attitudes were expressed for items 8, 20, and 22. A large majority of respondents felt that it was necessary to light freeways in urban areas where successive interchanges are in close proximity. With regard to items concerning the level of illumination (20) and variations in the level of illumination (22), a majority of respondents agreed with the AASHTO guidelines.

In summary, it appears that although there is general agreement with the AASHTO guidelines for lighting freeways, there is somewhat reluctant acceptance of the guidelines on the part of those respondents polled. Moreover, the most disagreement is centered around various design values necessary for the installation and operation of lighting systems. This disagreement points out needed research in the selection of such design values, or the determination of new, more valid quantitative criteria for the lighting of freeways.

Interchanges

Of the seven statements pertaining to the complete and partial lighting of interchanges (items 11, 13, 14, 18, 21, 24, and 30), only one (item 13) was strongly agreed with to a significant degree by the respondents. In this instance, 42 respondents strongly agreed and 35 agreed with the statement, pointing out the need for a consideration of the effects of sudden light change on drivers. A majority of positive responses was also evident for item 14, which concerned the reduction in visual contrast by commercial and industrial lighting systems adjacent to freeway interchanges. With regard to the remaining statements (11, 18, 21, 24, 30), general agreement was shown in all cases; however, again there appears to be an unwillingness on the part of the respondents to be strongly supportive of AASHTO guidelines. In several instances, although the majority of responses indicated a positive attitude, a significant number of respondents disagreed with the statement. For example, 15 respondents disagreed with the statement (21) that the lighting of channelized or divisional ramps is necessary. Ten disagreed with and seven were undecided about whether or not the level of illumination for ramps should correspond to the level of illumination for adjacent freeway traffic (18). This pattern was repeated for almost every statement concerned with the lighting of interchanges and is indicative of widely differing opinions regarding the lighting of such facilities.

Streets and Highways Other Than Freeways

AASHTO (*1*) has noted that "adequate street and highway lighting is justified by the resulting benefits, both tangible and intangible, to the general public." AASHTO has wisely stated, however, that "it is not practical at this time to establish specific warrants for the installation of roadway lighting to satisfy all prevailing conditions." The truth of this statement is evidenced by the lack of workable, objective criteria for the installation of street and highway illumination systems. In no other area of lighting is the engineer required to use so much subjective judgment. The recommendations of AASHTO in this area of lighting further point out the need for relevant objective design criteria. Furthermore, this lack of quantitative lighting criteria is reflected in the responses to statements 7, 12, 26, 27, and 3 regarding the lighting of streets and highways other than freeways. For three of the five statements (7, 27, 3) the response distribution is somewhat scattered, and the number of "undecided" responses is unusually large. However, the responses to statements 12 and 26 point out the major role of lighting in urbanized areas and heavily traveled streets and highways. Not only do the highly positive responses to these statements serve to accent the greatest contribution of street lighting, they are also indicative of needed research in this area. Development of adequate design criteria and warrants should greatly reduce the incidence of crime, auto accidents, and pedestrian safety in urban areas.

Bridges, Underpasses, Overpasses, and Tunnels

The lighting of bridges, underpasses, and other related structures is one of the more specialized areas of lighting and illumination system design. Each structure is unique; therefore, generalities in lighting design are small in scope compared to applications of other lighting techniques. In this section of the questionnaire, one statement (item 1) was the reverse of its AASHTO counterpart; that is, it was stated in terms opposite to those in the AASHTO guidelines. Thus, those who disagreed with the statement agreed with the AASHTO guidelines. In this instance, 36 respondents indicated that they were in agreement with the statement concerning the necessity of supplemental lighting for underpasses 75 ft in length; however, 45 respondents were of the opinion that supplemental lighting was unnecessary. This polarization of responses is an indication of the lack of general design criteria for the lighting of certain highway structures. There appears to be little disagreement with the statement (31) regarding the necessity for three levels of illumination in long tunnels. A definite majority of respondents indicated they felt separate illumination levels were required for daytime entrance zones, daytime interior zones, and nighttime. A polarization of responses is also evident for two statements (15 and 28) concerning the lighting of bridges. There is obvious disagreement among respondents as to the necessity of lighting bridges when the approaches are unlighted and the lighting of bridges for aesthetic appeal. This significant disagreement provides further supportive evidence of the need for quantitative and general design criteria for the lighting of bridges, overpasses, and underpasses.

TABLE A-1

TOTAL SCORES OF RESPONDENTS FROM STATE HIGHWAY DEPARTMENTS, MUNICIPAL PUBLIC WORKS DEPARTMENTS, AND INDIVIDUAL EXPERTS

RESPONDENT NO.	SHD	PWD	IE
1	121	150	133
2	144	126	126
3	123	128	130
4	127	118	142
5	154	136	127
6	137	118	123
7	136	134	121
8	124	105	120
9	91	77	135
10	134	125	127
11	126	131	148
12	125	124	144
13	129	145	129
14	146	134	159
15	116	121	124
16	124	122	133
17	121	129	128
18	114	149	130
19	125	128	127
20	123	137	126
21	120	116	
22	127	129	
23	110	117	
24	128	146	
25	144	122	
26	135		
27	126		
28	140		
29	120		
30	130		
31	119		
32	116		
33	118		
34	119		
35	125		
36	136		
37	121		
38	143		
39	132		
40	156		
41	130		
42	137		
43	140		
44	112		
Avg. score	127.818	126.680	131.600
Over-all avg. score		128.348	

Summary

Based on an analysis of the questionnaire, there appear to be several conclusions that may be drawn regarding the sufficiency of the AASHTO guidelines. Most important, of the engineers surveyed, only a few appeared wholeheartedly supportive of the AASHTO guidelines as they now stand. Although there is general agreement with these guidelines, the responses of the individuals indicate several areas in which improvement is needed. There is a definite need for development of relevant, objective design criteria for the

TABLE A-2

SUMMARY OF RESPONSES

QUESTION	GROUP TYPE [a]	NUMBER OF RESPONDENTS ANSWERING: STRONGLY AGREE	AGREE	UNDECIDED	DISAGREE	STRONGLY DISAGREE	$\bar{X}$	S^2
(a) Statements Pertaining to Freeways								
2. If traffic volume is the only consideration, continuous freeway lighting is only justified for sections of freeway in urban and suburban areas where the average daily traffic (ADT) count is 60,000 or greater.	SHD	4	7	6	19	1	2.54	1.509
	PWD	1	7	2	12	3	2.48	1.260
	IE	1	3	4	7	5	2.40	1.410
	All	6	17	12	38	9		
4. Continuous freeway lighting is desirable if local streets adjacent to the freeway are lighted and are visible from the freeway.	SHD	14	24	3	2	1	4.09	0.782
	PWD	6	15	2	2	0	4.00	0.667
	IE	8	10	1	1	0	4.25	0.618
	All	28	49	6	5	1		
5. One case where a continuous freeway lighting system is justified occurs where the width of the roadway is restricted for some significant reason.	SHD	14	20	6	4	0	4.00	0.837
	PWD	8	13	2	2	0	4.08	0.743
	IE	9	10	1	0	0	4.40	0.357
	All	31	43	9	6	0		
6. Continuous freeway lighting is necessary when the freeway passes through residential, commercial, or industrial areas that are lighted.	SHD	9	27	2	5	1	3.86	0.911
	PWD	6	14	2	3	0	3.92	0.827
	IE	9	9	2	0	0	4.35	0.450
	All	24	50	6	8	1		
8. In urban areas where several successive interchanges are in close proximity to one another, it is desirable to incorporate a continuous freeway lighting system.	SHD	22	20	0	1	1	4.38	0.661
	PWD	13	11	1	0	0	4.44	0.507
	IE	8	11	1	0	0	4.35	0.345
	All	43	42	2	1	1		
10. When cross streets, some of which are lighted, intersect with a freeway at relatively short intervals, the freeway should be lighted continuously.	SHD	11	16	11	5	1	3.70	1.096
	PWD	6	15	3	1	0	4.04	0.540
	IE	6	13	1	0	0	4.25	0.303
	All	23	44	15	6	1		
20. The level of illumination for continuous freeway lighting conditions should not be less than 0.6 footcandles average.	SHD	20	16	4	4	0	4.18	0.896
	PWD	11	11	1	2	0	4.24	0.773
	IE	10	4	2	2	2	3.90	1.989
	All	41	31	7	8	2		
22. It is desirable to minimize variation in the level of illumination or in the uniformity ratio on a continuously lighted freeway.	SHD	24	17	0	3	0	4.41	0.666
	PWD	8	13	1	3	0	4.04	0.873
	IE	7	10	2	1	0	4.15	0.661
	All	39	40	3	7	0		
23. For continuous freeway lighting installations, the average-to-minimum uniformity of illumination ratio should approach 3:1.	SHD	16	22	2	2	2	4.09	1.105
	PWD	4	13	6	2	0	3.76	0.690
	IE	8	9	2	0	0	4.20	0.695
	All	28	44	10	4	2		
25. Continuous freeway lighting is justified where, for a length of two or more miles, the freeway passes through a highly developed urban or suburban area.	SHD	8	23	5	6	2	3.66	1.160
	PWD	3	17	2	3	0	3.80	0.666
	IE	6	11	8	0	0	4.15	0.450
	All	17	51	15	9	2		
29. Continuous freeway sections with a high night-to-day accident ratio should be lighted.	SHD	14	23	5	2	0	4.11	0.615
	PWD	7	14	3	1	0	4.08	0.576
	IE	8	12	0	0	0	4.40	0.253
	All	29	49	8	3	0		
(b) Statements Pertaining to Interchanges								
11. Where crossroad approaches are lighted, the crossroad through traffic lanes should also be lighted at approximately the same level.	SHD	11	25	4	3	1	3.95	0.835
	PWD	4	14	2	5	0	3.68	0.977
	IE	7	11	1	1	0	4.20	0.589
	All	22	50	7	9	1		
13. Consideration should be given to reducing the effects of sudden light change on drivers as they enter and exit a partially lighted interchange.	SHD	18	19	4	2	1	4.14	0.881
	PWD	13	11	0	1	0	4.44	0.507
	IE	11	5	3	1	0	4.30	0.853
	All	42	35	7	4	1		

TABLE A-2 (Continued)

QUESTION	GROUP TYPE [a]	NUMBER OF RESPONDENTS ANSWERING: STRONGLY AGREE	AGREE	UNDECIDED	DISAGREE	STRONGLY DISAGREE	$\bar{X}$	S^2
14. The lighting of an interchange is justified when lights from commercial or industrial developments create visibility problems for drivers on the interchange.	SHD	18	23	0	2	1	4.25	0.750
	PWD	10	11	1	3	0	4.12	0.943
	IE	10	8	2	0	0	4.40	0.463
	All	38	42	3	5	1		
18. The level of illumination for ramps where complete interchange lighting is provided should correspond to the illumination level for freeway through traffic.	SHD	8	33	1	2	0	4.07	0.391
	PWD	4	12	4	5	0	3.60	1.000
	IE	5	9	3	3	2	3.80	1.011
	All	17	54	8	10	2		
21. When raised channelizing or divisional islands are located at the intersections of ramp terminals with a crossroad, partial interchange lighting is justified.	SHD	11	17	3	13	0	3.59	1.364
	PWD	4	17	2	2	0	3.92	0.576
	IE	5	10	4	0	1	3.70	1.484
	All	20	44	9	15	1		
24. The task of partial interchange lighting should be to illuminate the through traffic lanes and speed change lanes at diverging and merging locations.	SHD	13	24	3	3	1	4.02	0.860
	PWD	3	17	2	3	0	3.80	0.666
	IE	9	9	0	2	0	4.25	0.829
	All	25	50	5	8	1		
30. One instance where an interchange should be lighted is when the crossroads of that interchange are lighted for ½ mile or more on either side.	SHD	8	26	6	3	1	3.75	1.122
	PWD	3	21	0	1	0	4.04	0.290
	IE	4	13	3	0	0	4.05	0.366
	All	15	60	9	4	1		
(*c*) Statements Pertaining to Highways Other Than Freeways								
3. The application of transitional lighting in freeway lighting situations will enhance driver comfort and expedite traffic operations.	SHD	11	21	7	5	0	3.86	0.864
	PWD	6	15	2	2	0	4.00	0.667
	IE	11	6	1	0	0	4.30	0.957
	All	28	42	10	7	0		
7. Rural intersections with raised channelization or divisional islands may require a greater illumination level than what is normally applicable.	SHD	12	16	5	10	1	3.63	1.399
	PWD	5	17	1	2	0	4.00	0.583
	IE	8	7	2	3	0	4.00	1.157
	All	25	40	8	15	1		
12. Street lighting in general will contribute substantially to the efficiency, safety, and comfort of vehicular and pedestrian traffic in urban areas.	SHD	22	17	3	1	1	4.32	0.780
	PWD	17	8	0	0	0	4.68	0.226
	IE	12	7	1	0	0	4.55	0.360
	All	51	32	4	1	1		
26. Lighting should be provided for major arterials in urbanized areas, where the night-to-day accident ratio is high.	SHD	21	22	1	0	0	4.45	0.300
	PWD	11	13	0	1	0	4.36	0.490
	IE	13	7	0	0	0	4.65	0.239
	All	45	42	1	1	0		
27. At locations where unusual weather conditions exist (i.e., abnormal amounts of fog, ice, or snow) lighting should be installed for the purpose of alleviating potential traffic problems.	SHD	8	16	11	9	0	3.52	1.046
	PWD	6	15	4	0	0	4.08	0.410
	IE	8	8	4	0	0	4.20	0.589
	All	22	39	19	9	0		
(*d*) Statements Pertaining to Underpasses, Overpasses, Bridges, and Tunnels								
1. Supplemental lighting is really not necessary for underpasses under 75 ft in length, with respect to traffic operations.	SHD	5	22	6	10	1	3.45	1.091
	PWD	1	7	2	12	3	2.64	1.323
	IE	2	8	0	6	4	2.90	1.989
	All	8	37	8	28	8		
9. Short underpasses can be adequately lighted from luminaires positioned outside the underpasses.	SHD	5	27	4	8	0	3.65	0.834
	PWD	4	11	4	5	1	3.32	1.727
	IE	1	11	2	4	2	3.25	1.355
	All	10	49	10	17	3		
15. One justification for lighting long bridges should be aesthetic appeal.	SHD	3	10	8	15	8	2.73	1.459
	PWD	0	5	4	13	3	2.44	0.923
	IE	1	8	3	6	2	3.00	1.368
	All	4	23	15	34	13		

TABLE A-2 (Continued)

QUESTION	GROUP TYPE [a]	NUMBER OF RESPONDENTS ANSWERING: STRONGLY AGREE	AGREE	UNDECIDED	DISAGREE	STRONGLY DISAGREE	$\bar{X}$	S^2
16. Tunnels within the range of 100 to 500 ft should have two levels of illumination (i.e., night and day).	SHD	11	21	7	5	0	3.86	0.865
	PWD	9	7	4	5	0	3.80	1.333
	IE	8	8	1	3	0	4.05	1.103
	All	28	36	12	13	0		
19. Bridges and overpasses should be lighted at the same level of illumination and uniformity ratio as other roadway areas adjoining the bridge.	SHD	11	31	0	2	0	4.16	0.416
	PWD	5	15	1	4	0	3.84	0.890
	IE	4	11	0	4	1	3.65	1.397
	All	20	57	1	10	1		
28. From the perspective of traffic operations, there is little if any advantage to providing fixed-source lighting on long bridges, even though the approaches are unlighted.	SHD	1	20	4	12	7	2.91	1.387
	PWD	0	5	5	13	2	2.52	0.843
	IE	0	0	2	13	5	1.85	0.345
	All	1	25	11	38	14		
31. Three levels of illumination are required for long tunnels:								
(a) One for daytime entrance zones	SHD	17	22	2	2	1	4.27	0.389
	PWD	9	14	0	2	0	4.20	0.366
	IE	14	6	0	0	0	4.70	0.221
	All	40	42	2	4	1		
(b) One for daytime interior zones.	SHD	13	23	3	4	1	3.98	0.953
	PWD	7	14	1	3	0	4.00	0.833
	IE	11	9	0	0	0	4.55	0.261
	All	31	46	4	7	1		
(c) One for night.	SHD	13	25	3	2	1	4.07	0.763
	PWD	8	13	2	2	0	4.08	0.743
	IE	8	10	0	0	2	4.10	1.358
	All	29	48	5	4	3		

[a] SHD = state highway departments; PWD = municipal public works departments; IE = individual experts.

installation of lighting systems on freeways, interchanges and intersections, and streets and highways other than freeways. Furthermore, warranting criteria of an empirical nature need to be determined and established on the basis of objectively obtainable information. This would make it possible to greatly facilitate the setting of lighting job priorities and lighting system design. In addition, quantitative guidelines are required and should be developed for bridges and other specialized structures.

Guidelines and Practices

State Highway Departments

Twenty questions (34-53) in the state highway department questionnaire were used to obtain data on guidelines and practices. These data are summarized and discussed in the following.

Lighting Intensity (Q. 34).—This question asked for the average, minimum, and maximum intensities, in terms of horizontal footcandles, that are used in establishing a design. Table A-3 summarizes the responses from the 44 states that replied. Some misunderstanding is evidenced in the tabulation; there was confusion as to the meanings of maximum intensity. The research agency staff desired maximum and minimum design specifications, but some respondents answered in terms of maximum average and minimum average intensities.

Pavement Brightness (Q. 35).—None of the 44 states responding indicated that pavement brightness is not specified in design.

Glare (Q. 36).—As with Question 35, none of the 44 states responding specify a maximum disability glare at driver's eye level. They are of the opinion either that the state of the art is not sufficient to make such a specification, or that it can be adequately controlled through other design considerations (such as choice of luminaire cut-off).

Factors Used to Determine Mounting Height (Q. 37).—This question requested a listing of those factors that determined mounting height specifications in the most recent lighting installations. The responses are given in Table A-4. When asked if these factors differed with the class of roadway, 12 states responded yes, 32 states responded no. Of those responding yes, 6 cited standard practice, 2 cited utilization of existing utility poles, and one cited aesthetics, maintenance, economics, roadway width, land use, or installed by others.

Spacing Between Supports (Q. 38).—This question asked how the spacing between luminaire supports is de-

TABLE A-3

ILLUMINATION INTENSITIES USED BY THE VARIOUS STATE HIGHWAY DEPARTMENTS [a]

		ILLUMINATION INTENSITY (FC)								
		AVERAGE			MAXIMUM			MINIMUM		
ROADWAY LIGHTING CLASSIFICATION	LOCATION [b]	MEAN	RANGE	NO.[c]	MEAN	RANGE	NO.[c]	MEAN	RANGE	NO.[c]
Continuous freeway	U	0.9	0.5–2.0	36	2.6	0.6–10.0	17	0.5	0.2–0.8	25
	S	0.9	0.6–2.5	36	2.4	0.6–5.0	16	0.4	0.2–0.8	23
	R	0.9	0.6–2.0	31	2.3	0.6–10.0	13	0.4	0.1–0.8	21
Continuous arterial street	U	1.2	0.6–2.4	30	1.9	0.8–5.0	13	0.6	0.3–0.9	21
	S	0.9	0.6–2.0	29	1.5	0.6–3.5	12	0.5	0.1–0.8	20
Freeway interchanges	U	1.0	0.6–2.0	36	2.5	0.6–10.0	17	0.5	0.2–1.0	25
	S	0.9	0.5–2.0	34	2.2	0.6–10.0	16	0.6	0.2–3.5	23
	R	0.8	0.5–2.0	33	2.2	0.6–10.0	15	0.4	0.2–0.8	23
Arterial interchanges	U	1.1	0.5–2.4	28	2.0	0.6–5.0	13	0.6	0.2–0.8	20
	S	0.9	0.5–2.0	28	1.8	0.6–3.5	13	0.4	0.1–0.8	20

[a] Summary of responses to Question 34.
[b] U = urban; S = suburban; R = rural.
[c] Number of responses.

termined. The responses are summarized in Table A-5.

Geometric Configuration of Lighting System (Q. 39).—This question was divided into three parts. The first part requested factors that determine geometric configuration of luminaire supports (i.e., median, staggered, opposite, etc.). The responses to this part are given in Table A-6.

The second part requested preferences as to the use and reasons for use of median, staggered, opposite, and one-side mounting arrangements. These responses are given in Table A-7.

The third part apparently was confused with the second; therefore, it is not tabulated.

Light Sources (Q. 40).—This question asked for specifications as to the type and power of lamps used for various roadway classifications. Clear mercury vapor lamps of 400- 700- and 1,000-w power are the preferred types (Table A-8). It is interesting to note that considerable use is being made of high-pressure sodium and multi-vapor sources.

Mounting Height (Q. 41, 42, 43).—These three questions covered the mounting height used, including the highest, that normally used, and anticipated use. The results are given in Table A-9. It is significant to note the trend to higher mounting heights, especially between 30 and 50 ft and more than 100 ft.

Line Voltages (Q. 44).—This question asked for the line voltage normally specified in state lighting installations. Table A-10 summarizes the responses. When asked if electric utility companies assisted in this specification, 27 states replied yes. Of the yes respondents, 8 cited design assistance, 10 cited furnish power only, 4 cited provide transformers only, and 3 cited substantially.

Maintenance (Q. 45, 46, 47, 48).—These questions requested, respectively, time intervals for cleaning and relamping of lighting installations, the individual responsible for this maintenance, indications of difficulties with particular mountings and mounting heights, and lamp problems.

TABLE A-4

FACTORS DETERMINING MOUNTING HEIGHTS USED BY THE STATES [a]

FACTOR	STATES RESPONDING (NO.)
Economics	17
Uniformity	16
Safety	10
Standard practice	9
Roadway width	8
Maintenance	8
Glare control	6
Lamp output	5
Geometrics	3
Existing lighting	3
Aesthetics	2
Traffic volume	1

[a] Summary of responses to Question 37.

TABLE A-5

METHODS USED BY THE STATES TO DETERMINE LUMINAIRE SPACING [a]

METHOD	STATES RESPONDING (NO.)
Coefficient of utilization formula	28
Uniformity ratio	16
Lamp output	7
Geometrics	6
Isofootcandle overlay	5
Roadway width	5
Mounting height/spacing ratio	4

[a] Summary of responses to Question 38.

TABLE A-6

FACTORS THAT DETERMINE LIGHTING SYSTEM GEOMETRIC CONFIGURATION USED BY THE STATES [a]

FACTOR	STATES RESPONDING (NO.)
Roadway width	24
Facility geometrics	12
Uniformity	12
Median width	10
Economics	9
Safety	6
Light intensity	5
Aesthetics	3
Mounting height	2

[a] Summary of responses to Question 39a.

TABLE A-7

STATE PREFERENCES AND REASONS FOR VARIOUS GEOMETRIC CONFIGURATIONS [a]

	STATES RESPONDING (NO.)			
FACTOR	MEDIAN	STAGGERED	OPPOSITE	ONE-SIDE
Would not use	30	9	28	3
Better uniformity	1	26	1	3
Economics	0	8	0	5
Median considerations	8	4	0	4
Higher intensity	0	0	5	0
Geometric considerations	0	0	9	5
Delineation	0	1	0	2
Other factors	0	0	0	3

[a] Summary of responses to Question 39b.

The responses are summarized in Tables A-11, A-12, and A-13, respectively. In Table A-11, the large number of states having no regular maintenance schedule is surprising, considering the importance of maintenance in roadway lighting. In Table A-12 it is interesting that only four states perform all of their own maintenance. The items of interest in Table A-13 are the problems associated with heights greater than 30 ft.

Traffic Volumes (*Q. 49, 50, 51, 52*).—The state highway departments were given an opportunity in these questions to express their views concerning traffic volume as a warranting condition. Table A-14 summarizes these responses.

Luminaire Support Bases (*Q. 53*).—Unless appropriate safety measures are included in lighting practices, much of the lighting designer's work can be for naught. This question requested information to determine safety practices involving luminaire support bases. Table A-15 summarizes the use of various base types by the state highway departments. It is gratifying to note the safety consciousness of the state highway departments as indicated by their use of acceptable breakaway features.

Municipal Public Works Departments

A questionnaire survey was also made of the largest municipality in each of the 50 states. The questionnaire was constructed to yield basically the same information as that desired from the state highway departments. The first 32 items were identical to corresponding items in the state questionnaire. The remaining questions (33-52), covering specific guidelines and practices in municipal applications, are discussed in the following. A total of 25 cities responded to the questionnaire.

TABLE A-8

STATE HIGHWAY DEPARTMENT USE OF VARIOUS LAMP TYPES AND POWER [a]

LAMP TYPE	ROADWAY LIGHTING CLASSIFICATION	STATES USING (NO.)				
		175 w	250 w	400 w	700 w	1,000 w
Clear mercury vapor	Cont. freeways	0	1	14	16	18
	Cont. arterials	0	1	20	11	12
	Full interchange	0	1	21	11	12
	Safety lighting	1	4	24	9	5
Color-improved mercury vapor	Cont. freeways	0	0	2	1	2
	Cont. arterials	0	0	4	1	1
	Full interchange	0	0	3	1	2
	Safety lighting	0	1	3	0	1
High-pressure sodium	Cont. freeways	—	1	6	—	—
	Cont. arterials	—	1	7	—	—
	Full interchange	—	1	8	—	—
	Safety lighting	—	2	6	—	—
Metal halide; multi-vapor	Cont. freeways	—	—	1	—	4
	Cont. arterials	—	—	1	—	3
	Full interchange	—	—	1	—	6
	Safety lighting	—	—	0	—	3

[a] Summary of responses to Question 40.

TABLE A-9

MOUNTING HEIGHTS USED BY STATE HIGHWAY DEPARTMENTS[a]

ROADWAY LIGHTING CLASSIFICATION	LAMP POWER (W)	STATES USING (NO.) FOR MOUNTING HEIGHT OF ≤ 30 FT	31–35 FT	36–40 FT	41–45 FT	46–50 FT	51–99 FT	≥ 100 FT
(a) Highest								
Continuous freeways	400	12	4	17	2	0	0	0
	700	0	0	10	4	6	0	0
	1000	0	0	3	3	9	1	1
Continuous arterials	400	12	4	14	0	0	0	0
	700	0	0	9	5	5	0	0
	1000	1	0	2	3	6	1	1
Full interchange	400	16	6	14	1	0	0	2
	700	0	0	4	0	4	0	0
	1000	0	1	3	1	5	1	10
Safety lighting	400	17	6	15	1	1	0	1
	700	0	0	4	0	4	0	0
	1000	0	0	3	1	5	1	2
(b) Normal								
Continuous freeways	400	12	3	15	0	0	0	0
	700	0	0	11	4	4	0	0
	1000	0	0	4	3	10	1	1
Continuous arterials	400	14	4	10	0	0	0	0
	700	0	0	12	1	3	0	0
	1000	1	0	1	11	7	1	1
Full interchange	400	15	5	12	0	0	0	1
	700	0	0	14	3	3	0	0
	1000	1	0	3	3	6	0	8
Safety lighting	400	20	4	10	0	0	0	0
	700	0	0	7	1	3	0	0
	1000	0	0	2	1	5	1	0
(c) Anticipated Use of Higher Mounts								
Continuous freeways	400	1	2	4	2	5	1	0
	700	0	1	2	0	5	0	0
	1000	0	0	0	0	9	4	5
Continuous arterials	400	1	2	2	1	0	0	1
	700	0	0	2	1	6	1	0
	1000	0	0	0	0	7	2	3
Full interchange	400	0	2	4	2	2	1	1
	700	0	1	2	0	3	0	0
	1000	0	0	0	0	4	3	20
Safety lighting	400	0	2	5	2	4	0	0
	700	0	1	3	0	4	1	0
	1000	0	0	0	0	4	4	5

[a] Summary of responses to Questions 41, 42, 43.

Lighting Intensity (*Q. 33*).—As a general rule, levels of lighting intensity on the municipality questionnaires are somewhat higher than those on the state questionnaires. These responses are probably influenced by the higher recommended values given in the ASA Standard Practice. Table A-16 summarizes the city responses.

Pavement Brightness (*Q. 34*).—As with the state highway departments; none of the responding municipalities specify pavement brightness as a design criterion or standard.

Glare (*Q. 35*).—Again, none of the municipal respon-

TABLE A-10

LINE VOLTAGE SPECIFIED FOR STATE LIGHTING INSTALLATIONS[a]

VOLTAGE	STATES RESPONDING (NO.)
480	34
240/480	23
277	3
207	1
120	3

[a] Summary of responses to Question 44.

dents specify a permitted level of disability glare at driver's eye level.

Factors Used to Determine Mounting Height (Q. 36).— Table A-17 gives the factors indicated by the cities as being those required for determining luminaire mounting heights in their most recent installations. The factors are similar to those reported by the state highway departments. The three most frequently listed factors are lamp power, stan-

TABLE A-11

CLEANING AND RELAMPING MAINTENANCE, STATE HIGHWAY DEPARTMENTS [a]

ROADWAY LIGHTING CLASSIFICATION	STATES RESPONDING (NO.)					
	6–12 MONTHS	12–24 MONTHS	24–36 MONTHS	36–48 MONTHS	> 48 MONTHS	NO SCHEDULE
Continuous freeways	8	4	3	7	3	19
Continuous arterials	5	3	6	8	1	22
Full interchange	6	4	3	11	4	17
Safety lighting	6	5	2	8	1	20

[a] Summary of responses to Question 45.

TABLE A-12

PARTY RESPONSIBLE FOR MAINTENANCE OF STATE HIGHWAY LIGHTING [a]

PARTY RESPONSIBLE	PERCENTAGE OF TOTAL INSTALLATIONS	STATES RESPONDING (NO.)
State Highway Department	100	4
Local Companies	100	24
Local Companies	90	2
Local Companies	85	1
Local Companies	75	2
Local Companies	50	1
Local Companies	10	1

[a] Summary of responses to Question 46.

TABLE A-13

LIGHTING SYSTEM MAINTENANCE PROBLEMS, STATE HIGHWAY DEPARTMENTS [a]

PROBLEM	STATES RESPONDING (NO.)
Maintenance of heights over 30 ft	9
Pole vibration	2
Painted poles	1
High-pressure sodium not starting	1
Short life of fluorescent	2
Short life of metal halide	1

[a] Summary of responses to Questions 47, 48.

TABLE A-14

DESIRED TRAFFIC VOLUME FOR INSTALLATION OF LIGHTING BY STATE HIGHWAY DEPARTMENTS [a]

ROADWAY LIGHTING CLASSIFICATION	WHERE ADT MEAS.	LOCATION [b]	STATES RESPONDING (NO.) FOR ADT OF							
			< 10,000	10,000–20,000	20,000–30,000	30,000–40,000	40,000–50,000	50,000–60,000	AASHTO	OTHER
Continuous freeways	Through	U	1	4	4	16	2	3	6	8
		S	1	3	10	10	2	1	7	10
		R	2	2	8	3	1	3	8	17
Full interchange	Ramp	U	10	18	2	0	0	0	7	7
		S	24	4	1	0	0	0	7	8
		R	25	1	1	0	0	0	8	9
Partial interchange	Through	U	3	6	20	0	0	0	7	8
		S	1	15	13	0	0	0	7	8
		R	4	22	1	1	0	0	7	9
	Ramp	U	27	1	0	0	0	0	7	9
		S	28	0	0	0	0	0	7	9
		R	27	1	0	0	0	0	7	9

[a] Summary of responses to Questions 49, 50, 51, 52.
[b] U = urban; S = suburban; R = rural.

dard practice, and maintenance, whereas the states most frequently listed economics, uniformity, and safety. When asked if these factors differed with the class of roadway, 14 states responded yes. The three predominant responses were: (1) Higher speeds call for increased heights; (2) Use standard height for each class of road; (3) Varies with the width of the road.

Spacing Between Supports (Q. 37).—The most frequently used factor for determining luminaire support spacing is the average illumination formula or coefficient of utilization formula. This was reported by 22 of the 25 cities responding. As a matter of comparison, 28 of the 44 states responding also reported this factor. Table A-18 summarizes the responses.

Geometric Configuration of Lighting System (Q. 38).—The first part of this question concerned those factors that determine the geometric configuration of luminaire supports. The cities' responses to this part are given in Table A-19. The second part involved the cities' preferences for the various geometric configurations. Table A-20 summarizes the results. The third part was confused with the second part and is, therefore, not tabulated.

Light Sources (Q. 39).—This question involved the cities' preference for various types and wattages of lamps. The results are similar to those from the state questionnaires, with 1,000-, 700-, and 400-w clear mercury vapor being the most popular. Complete results are given in Table A-21.

Mounting Height (Q. 40, 41, 42).—These three questions covered the mounting height used, including the highest, that normally used, and anticipated use. The results are given in Table A-22. It is significant to note a trend toward higher heights, similar to those found in the state highway departments.

TABLE A-15

STATE HIGHWAY DEPARTMENT USE OF VARIOUS LUMINAIRE SUPPORT BASES [a]

BASE TYPE	STATES RESPONDING (NO.)			
	WITH GUARDRAIL		EXPOSED	
	HIGH SPEED	LOW SPEED	HIGH SPEED	LOW SPEED
(a) Steel flange	17	14	0	11
(b) Aluminum flange	18	17	12	17
(c) Steel transformer	9	8	0	8
(d) Aluminum transformer	23	20	36	31
(e) Progressive shear	2	1	5	3
(f) Slip	4	2	12	9

[a] Summary of responses to Question 53.

TABLE A-16

ILLUMINATION INTENSITIES USED BY THE VARIOUS MUNICIPALITIES [a]

ROADWAY LIGHTING CLASSIFICATION	LOCATION [b]	ILLUMINATION INTENSITY (FC)								
		AVERAGE			MAXIMUM			MINIMUM		
		MEAN	RANGE	NO.[c]	MEAN	RANGE	NO.[c]	MEAN	RANGE	NO.[c]
Freeways and expressways	U	1.2	0.6–2.0	15	2.2	1.0–5.0	8	0.7	0.2–1.0	7
	S	0.9	0.6–1.0	11	1.5	1.0–2.0	5	0.7	0.6–0.8	4
Arterials	U	1.6	0.6–2.0	18	6.1	2.0–16.0	9	0.9	0.5–1.5	8
	S	1.0	0.9–1.2	11	2.4	1.5–5.0	5	0.8	0.6–1.0	4
Collectors	U	1.1	0.5–2.0	18	2.2	0.9–5.0	8	0.7	0.4–1.2	8
	S	0.8	0.6–1.0	11	1.3	1.0–2.0	5	0.6	0.6	4
Locals	U	0.7	0.2–1.0	16	1.6	0.4–5.0	8	0.3	0.1–0.6	8
	S	0.4	0.2–0.8	11	0.9	0.6–0.9	5	0.4	0.2–0.6	4
Interchanges and intersections	U	1.5	0.6–3.0	12	2.8	1.0–5.0	8	0.9	0.5–1.2	7
	S	1.2	0.6–2.0	7	2.2	1.0–3.0	5	0.8	0.6–1.0	4

[a] Summary of responses to Question 33.
[b] U = urban; S = suburban.
[c] Number of responses.

TABLE A-17

FACTORS DETERMINING MOUNTING HEIGHT USED BY MUNICIPALITIES [a]

FACTOR	CITIES RESPONDING (NO.)
Lamp power	9
Standard practice	6
Maintenance	4
Trees	3
Roadway type	2
Roadway width	2
Cost	2
Existing lighting	2
Uniformity	2
Spacing	2
Manufacturer recommendations	2
Glare	2
IES guide	1
Aesthetics	1

[a] Summary of responses to Question 36.

TABLE A-18

METHODS USED BY THE CITIES TO DETERMINE LUMINAIRE SPACING [a]

METHOD	CITIES RESPONDING (NO.)
Coefficient of utilization formula	22
Trees and driveways	3
Spacing of existing utility poles	2

[a] Summary of responses to Question 37.

TABLE A-19

FACTORS THAT DETERMINE LIGHTING SYSTEM GEOMETRIC CONFIGURATIONS USED BY THE MUNICIPALITIES [a]

FACTOR	CITIES RESPONDING (NO.)
Roadway width	11
Cost	6
Restrictions (trees, driveways, etc.)	5
Safety	4
Lighting distribution	4
Lamp power	2
Pedestrian volume	2
Policy	2
Type of roadway	1

[a] Summary of responses to Question 38a.

TABLE A-20

MUNICIPAL PREFERENCES AND REASONS FOR VARIOUS GEOMETRIC CONFIGURATIONS [a]

	MUNICIPALITIES RESPONDING (NO.)			
FACTOR	MEDIAN	STAG-GERED	OPPO-SITE	ONE-SIDE
Economy	2	0	0	2
Safety	2	1	1	0
Uniformity	0	8	0	0
Higher intensity	0	0	4	0
Geometry	1	5	5	0
Maintenance	0	1	0	0
Other factors	1	1	1	2

[a] Summary of responses to Question 38b.

Line Voltages (*Q. 43*).—This question asked for the line voltage normally specified in city lighting installations. Table A-23 summarizes the responses. Of the cities responding, 19 indicated that the electric utility companies assisted in the voltage specifications.

Maintenance (*Q. 44, 45, 46, 47*).—This series of questions involved the cities' maintenance practice and problems. Table A-24 gives maintenance schedules for cleaning and relamping as practiced by the cities. Table A-25 gives the party responsible for maintenance. Table A-26 summarizes the maintenance problems being experienced by the cities.

Traffic Volumes (*Q. 48*).—None of the cities responding indicated that traffic volume is used in determining when to light the various classifications of roadways.

Luminaire Support Bases (*Q. 49*).—This question was designed to obtain information on the use of various pole bases. The results are quite different from those obtained from the states. A large number of cities reported use of exposed unsafe bases under high-speed conditions. Complete results are given in Table A-27.

TABLE A-21

MUNICIPALITY USE OF VARIOUS LAMP TYPES AND POWER [a]

LAMP TYPE	ROADWAY LIGHTING CLASSIFICATION	MUNICIPALITIES USING (NO.)				
		175 w	250 w	400 w	800 w	1,000 w
Clear mercury vapor	Freeways and expressways	0	0	8	3	9
	Arterials	0	0	16	4	4
	Collectors and locals	11	5	8	0	0
	Interch. and intersect.	2	2	8	0	8
Color-improved mercury vapor	Freeways and expressways	1	1	1	1	1
	Arterials	1	1	4	2	1
	Collectors and locals	6	3	1	0	0
	Interch. and intersect.	1	4	3	2	0

[a] Summary of responses to Question 39.

TABLE A-22

MOUNTING HEIGHTS USED BY MUNICIPALITIES[a]

ROADWAY LIGHTING CLASSIFICATION	LAMP POWER (W)	MUNICIPALITIES USING (NO.), FOR MOUNTING HEIGHT OF				
		≤ 30 FT	31–40 FT	41–50 FT	51–60 FT	≥ 100 FT
(a) Highest						
Freeways and expressways	400	7	9	2	0	0
	700	1	5	1	0	0
	1000	1	5	4	1	0
Continuous arterial	400	13	10	0	0	0
	700	4	6	0	0	0
	1000	1	10	1	0	0
Collectors and locals	400	13	7	0	0	0
	700	1	1	0	0	0
	1000	0	3	0	1	0
Interchanges and intersections	400	11	8	1	0	0
	700	1	6	0	0	0
	1000	0	7	0	1	0
(b) Normal						
Freeways and expressways	400	11	7	1	0	0
	700	2	6	0	0	0
	1000	1	5	3	0	0
Continuous arterial	400	17	6	0	0	0
	700	3	5	0	0	0
	1000	1	8	1	0	0
Collectors and locals	400	18	5	0	0	0
	700	2	2	0	0	0
	1000	1	3	1	0	0
Interchanges and intersections	400	13	4	1	0	0
	700	2	4	0	0	0
	1000	0	5	2	0	0
(c) Anticipated Use of Higher Mounts						
Freeways and expressways	400	0	4	3	0	0
	700	0	1	1	1	0
	1000	0	1	3	1	1
Continuous arterial	400	1	5	1	0	0
	700	0	3	0	1	0
	1000	0	3	2	2	0
Collectors and locals	400	1	4	0	0	0
	700	0	2	0	0	0
	1000	0	1	1	0	0
Interchanges and intersections	400	0	4	12	0	2
	700	0	12	0	1	2
	1000	0	0	2	2	5

[a] Summary of responses to Questions 40, 41, 42.

TABLE A-23

LINE VOLTAGES SPECIFIED FOR MUNICIPAL LIGHTING INSTALLATIONS[a]

VOLTAGE	MUNICIPALITIES RESPONDING (NO.)
480	2
240	6
120	4
240/480	4
120/240/277/480	2
120/240	1
120/208	1
Det. by utility company	2

[a] Summary of responses to Question 43.

TABLE A-24

CLEANING AND RELAMPING MAINTENANCE, MUNICIPAL PUBLIC WORKS DEPARTMENTS[a]

ROADWAY LIGHTING CLASSIFICATION	MUNICIPALITIES RESPONDING (NO.) 6–12 MONTHS	12–24 MONTHS	24–36 MONTHS	36–48 MONTHS	> 48 MONTHS	NO SCHEDULE
Freeways	8	3	2	5	3	6
Arterials	9	3	2	5	3	5
Collectors and locals	9	3	2	5	3	5
Interchanges and intersections	9	3	2	5	3	5

[a] Summary of responses to Question 44.

TABLE A-25

PARTY RESPONSIBLE FOR MAINTENANCE OF MUNICIPAL LIGHTING SYSTEM[a]

PARTY RESPONSIBLE	PERCENTAGE OF TOTAL INSTALLATIONS	MUNICIPALITIES RESPONDING (NO.)
City	100	6
City	20	1
Local uilities	100	13
Local utilities	80	1
Private contractor	100	2

[a] Summary of responses to Question 45.

TABLE A-26

LIGHTING SYSTEM MAINTENANCE PROBLEMS, MUNICIPALITIES[a]

PROBLEM	MUNICIPALITIES RESPONDING (NO.)
Mounting heights over 35 ft	1
Low-mounted rail lighting	1
Pole vibration	1
Short life of metal vapor	1
Short life of high-pressure sodium	1
Fluorescents hard to maintain	1

[a] Summary of responses to Questions 46, 47.

TABLE A-27

MUNICIPAL PUBLIC WORKS DEPARTMENT USE OF VARIOUS LUMINAIRE SUPPORT BASES[a]

BASE TYPE	WITH GUARDRAIL HIGH SPEED	WITH GUARDRAIL LOW SPEED	EXPOSED HIGH SPEED	EXPOSED LOW SPEED
(a) Steel flange	8	4	5	8
(b) Aluminum flange	7	3	7	7
(c) Steel transformer	7	6	8	11
(d) Aluminum transformer	7	3	8	7
(e) Progressive shear	1	1	3	2
(f) Slip	0	0	0	0
(g) Other	1	1	3	3

[a] Summary of responses to Question 49.

APPENDIX B

FIELD STUDY PROCEDURES AND QUESTIONNAIRES

Chapter Two provides a conceptual framework on which to develop the characteristics of the suitable visual environment. In this connection, the field studies reported in this appendix outline the development of the characteristics and how they relate to the various objectives of the research program.

PURPOSE OF FIELD STUDIES

The field studies served a multi-purpose function, as follows:

1. To develop further driver visual information needs, especially as related to characteristics of specific traffic facilities.
2. To validate the conceptualization of traffic facility classification (developed in Chapter Two).
3. To determine subjective comfort benefits of roadway lighting.
4. To provide information for warranting conditions and priorities for roadway lighting.
5. To provide information on design guidelines.

These purposes are discussed individually in the following.

Visual Information Needs

The section on "Visual Information Needs" (Chapter Two) has established, in rather gross ways, those visual needs associated with the various levels of driver performance. One of the functions of the field studies was the investigation of these, and possibly other informational needs, as they relate to night-driving task performance and to the geometric, operational, and environmental characteristics encountered on various traffic facilities. It was desired that the field studies provide some reinforcement of the informational needs and determine how often these needs arise on the various types of facilities.

Traffic Facility Classification

For any comprehensive lighting program, the first need is a method of classifying the street and highway system. Thus, the field studies served the function of testing the conceptualization of traffic facility classification as developed in Chapter Two.

Subjective Comfort Benefits

One of the objectives of the research program was to determine the benefits accruable to fixed lighting. Thus, the field studies were planned to evaluate one measure of fixed-lighting benefits, subjective driver comfort.

Warrants and Priorities

Although the field studies were concerned primarily with the requirements of the suitable visual environment, some emphasis was placed on the conditions warranting roadway lighting and priorities for installation of the same. It is evident that without visual task problems roadway lighting is not warranted. Conversely, as visual task problems become apparent, so does the need for fixed lighting and the more problems that can be solved by lighting, the higher the priority should be. Therefore, the field studies attempted to identify some of the conditions that warrant fixed lighting.

Design Guidelines

The field studies also were planned to reveal indications of what the design guidelines should be for various traffic facility situations. Efforts were made to select study sites with varying design conditions for comparison purposes.

STUDY PROCEDURES

Field Study Concepts

The complexity of the night-driving environment has required research concepts out of the ordinary for adequate study of the total system. Therefore, the methodology utilized in this effort involved unique approaches.

Among the names ascribed to the techniques of this research are "diagnostic studies," "team studies," and "driver task analysis studies." In actuality, all three are descriptive of the concepts involved. First, it was desired that the studies analyze the driving task informational needs and the resultant performance of the driver. Thus, driver task analysis studies were appropriate. Second, it was evident that some indication was needed as to the adequacy or inadequacy of the visual environment in providing necessary visual inputs. Therefore, an investigation or analysis of the cause or nature of a condition, situation or problem as related to the driving task was necessary (diagnostic studies). Third, it was desirable to involve as many people as possible in the development of the requirements of the visual environment. Thus, a team of participants, even similar to a medical team, was a part of the concept. The final description of the field study technique is "a team of individuals representing professionals and lay drivers diagnosing the cause or nature of conditions, situations, or problems relating to the driving task at night."

Selection of Study Sites

It was originally anticipated that study sites would be selected from throughout the United States. However, by mutual agreement with the sponsor, only two geographic areas—Atlanta, Ga., and Dallas, Tex.—were represented in the field studies. To accomplish the multi-purpose function of the field studies, it became necessary to choose individual study sites carefully to include as many traffic facility classifications and situations as possible.

Eight individual study sites were selected, four in each of the two geographical areas. From a traffic facility functional classification standpoint, these eight study sites incorporated the more important classifications discussed in Chapter Two. In addition, the sites were selected to be representative of the various geometric, operational, and environmental conditions expected on the various functional classifications. Thus, each study site and sections within each study site were classified according to the scheme discussed under "Traffic Facility Classification" (Chapter Two), and in so doing provided some indication of the adequacy of the classification scheme.

Details of each individual study site are discussed in later sections of this appendix.

Selection of Study Teams

Interdisciplinary teams were selected for each of the two geographic areas. Each team consisted of eight members, four representing various professional disciplines and the other four representing lay drivers. The general guidelines for selection of team members were as follows:

1. All subjects should have an outgoing personality.
2. Not more than three should be technically trained in highway, traffic, or illumination engineering.
3. At least two women should be included on the team.
4. It was desirable to have state and city representatives.
5. It was desirable to include someone in an administrative position in the highway department.

With these requirements as guidelines, the City of Dallas, Tex., and the Georgia Division of Highways were each requested to engage seven volunteers to serve as subjects on the study teams. The eighth member of each team was a staff psychologist from the Texas Transportation Institute. Details on each study team are given in later sections on the specific study areas.

Development of Questionnaires and Interview Procedures

Questionnaires were developed for use by the study team for two general classifications, as follows:

1. Freeways and expressways (including interchanges).
2. Arterials and major highways (including intersections).

These questionnaires, for completion by the study teams, consisted of questions pertaining to informational needs in the driving tasks. Primary emphasis in their development was given to visual task problems as related to geometric, operational, and environmental conditions. The questionnaire forms are given at the end of this appendix.

To assist in analysis of the driving task, interview forms were developed for use by the researchers. These forms outlined the various points that needed to be covered in the in-driving interviews.

Questionnaires also were developed for determining subjective comfort benefits ascribable to fixed roadway lighting. The final choice on design of this questionnaire was based on several criteria (see Appendix C).

STUDY SITE DESCRIPTIONS

Atlanta, Georgia (See Fig. B-1.)

A. Unlighted Arterial

The unlighted section of Peachtree-Industrial Road can be described as a suburban arterial street (Fig. B-2). Four distinct sections were included in the study site, as follows:

1. A four-lane undivided roadway approximately ¼ mile in length, including one major signalized intersection, several minor intersections, and one rather sharp sag vertical curve. Intermittent commercial development exists along the edge of the roadway.
2. A divided four-lane roadway approximately 0.6 miles in length, including two rather complicated channelized intersections (one with SR13 and one with the ramps from the diamond interchange with I-285. Some commercial development is present at the intersection.
3. A section approximately ½ mile in length that had just been opened to traffic. This section is a four-lane divided roadway that flares to a seven-lane divided section at the major intersections. The property adjacent to the study section has not yet been developed.
4. A ½-mile segment of SR13 extending from Peachtree-Industrial Road to SR23. The four-lane divided roadway has a wide median, serves two major automobile assembly plants, and contains three intersections with roadways leading into the parking areas for these plants. The parking lots at the assembly plants are lighted to a relatively high level, with considerable spillover onto the roadway. Although there is some glare from the light sources, it is not excessive. The last ¼ mile of this section is curbed, has an overpassing structure with virtually no clearance from the edges of the roadway, merges with a diamond slip ramp from I-285, and terminates in a lighted intersection with SR23. The roadway fronts on I-285 through the study section and the only development on the other side consists of the two large automobile assembly plants. Some commercial activity exists at the intersection with SR23.

B. Lighted Arterial

The lighted arterial study site (Fig. B-3) is divided into three sections based primarily on illumination characteristics, as follows:

1. An undivided four-lane roadway approximately ½ mile in length with a staggered lighting system having a mounting height of 40 ft and average pole spacing of 120 ft. The average-to-minimum illumination ratio is about 4:1 and the maximum-to-minimum ratio is 11:1. Strip commercial development exists on both sides of the roadway throughout the segment.
2. A divided four-lane roadway approximately 1¼ miles in length with turn bays at major intersections. The one-side lighting system has 400-w luminaires mounted at a height of 30 ft with average pole spacing of 110 ft. The average-to-minimum illumination ratio is 3:1 and the maximum-to-minimum ratio is 8:1. The development is primarily strip commmercial; however, a considerable por-

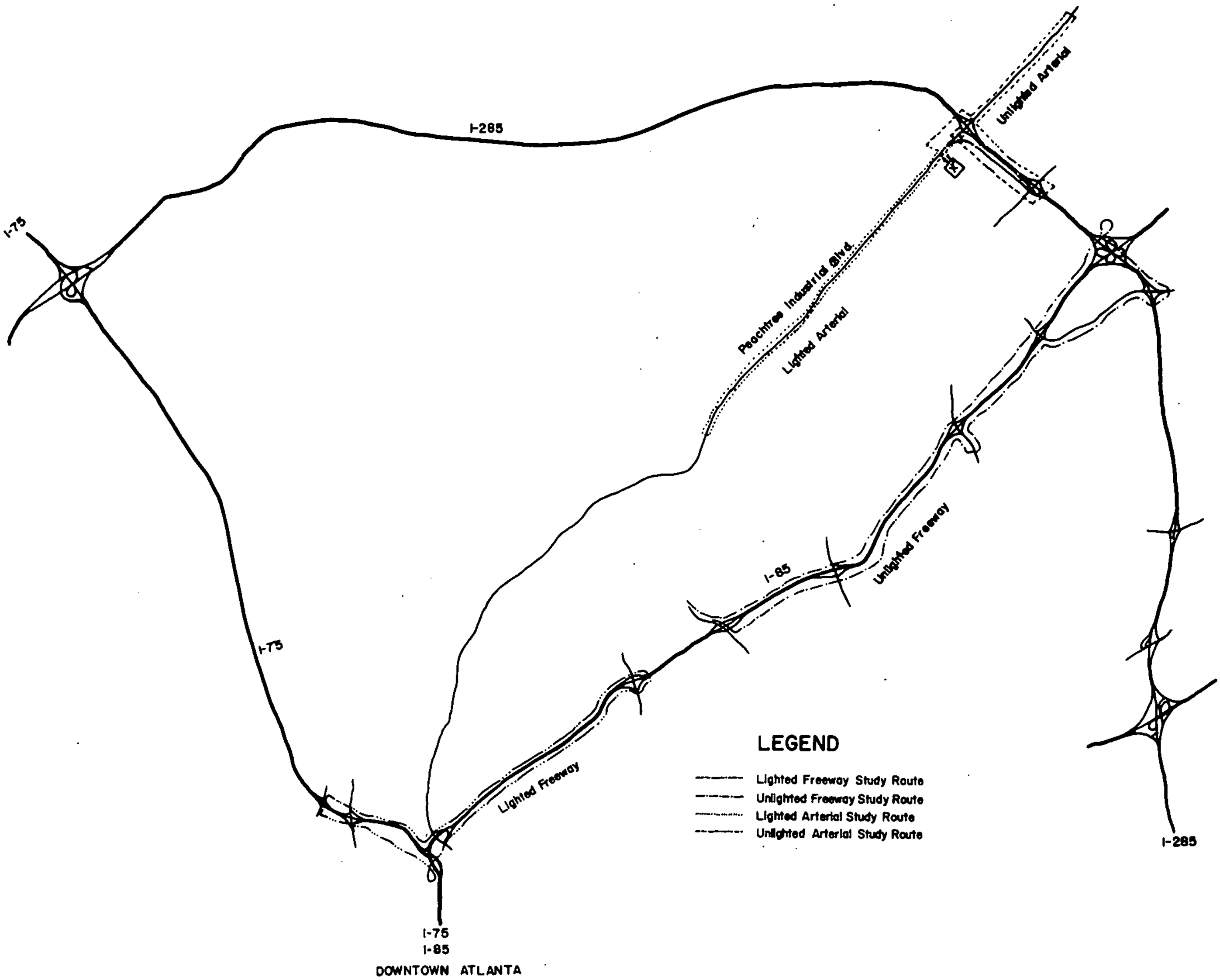


Figure B-1. Location of field study sites, Atlanta, Ga.

tion is undeveloped. Three major signalized intersections, several minor street intersections, and a number of private driveways are included in the segment.

3. A divided four-lane roadway with very narrow (10 ft) lanes and curbed on both the left and right. This segment is approximately 0.7 mile in length. The lighting system can best be described as "erratic." Lighting is provided from both sides, but no fixed pole spacing exists. Some of the luminaires are span-wire mounted. The luminaire mounting height varies from 23 ft to 30 ft. The orientation of the luminaires is not uniform, which results in a very spotted appearance. The luminaires are 400-w units with average spacing of about 200 ft. Average illumination is approximately 1.4 footcandles, with an average-to-minimum ratio of 14:1 and a maximum-to-minimum ratio of 41:1. The roadway is adjacent to Oglethorpe College and parallels a railroad throughout much of the segment. The last 0.2 mile contains strip commercial development along both sides.

C. Unlighted Freeway

A portion of I-85 and I-285, the site is essentially suburban in nature and residential development exists in close proximity to the freeway (Fig. B-4). Three distinct sections were included in the study site, as follows:

1. On the I-85 North section the majority of the environmental buildup is commercial and centered around two major interchanges (Shallowford Road and Chamblee-Tucker Road). Although there is significant illumination from these commercial areas, they are far enough removed from the roadway proper that they have little influence on the driver. The freeway section is a four-lane divided facility with a 36-ft grass median without barrier. The road shoulders are unpaved and are bordered by a guardrail.

2. A second section on I-85, I-285 involving a short, unlighted four-lane divided section with two interchanges, both with safety lighting.

INDUSTRIAL BLVD., SOUTHBOUND. FOUR-LANE DIVIDED ROADWAY, NO ENVIRONMENTAL BUILDUP.

PEACHTREE ROAD, SOUTHBOUND. FOUR-LANE UNDIVIDED, HEAVY ENVIRONMENTAL BUILDUP.

INTERCHANGE OF INDUSTRIAL BLVD. SOUTHBOUND & I 285, APPROACHING PEACHTREE ROAD.

PEACHTREE ROAD SOUTHBOUND. FOUR-LANE UNDIVIDED, 45 MPH SPEED LIMIT.

Figure B-2. Unlighted arterial study section, Atlanta, Ga.

3. A section on I-285, comprising a part of the loop around the Atlanta metropolitan area. It is located in a rural area with virtually no environmental buildup; includes one non-illuminated interchange, a partial cloverleaf.

D. Lighted Freeway

The illuminated freeway study site can be described primarily as a suburban freeway (Fig. B-5). Three distinct sections were included in the site, as follows:

1. A four-lane divided facility (I-85) approximately 4 miles in length, with a portion passing through an area of extremely heavy environmental buildup. The illumination system consists of 400-w clear mercury vapor sources mounted at 35 ft in a staggered configuration. Except for the one segment mentioned previously, there is little environmental buildup. This section has two minor interchanges and one major interchange. The median is approximately 30 ft wide with no median barrier.

2. The interchange of I-85 with I-75 is of the partial cloverleaf type. The illumination system consists of 400-w clear mercury vapor sources mounted at 35 ft in a one-sided configuration. This interchange has extremely critical geometrics; no acceleration lanes are provided.

3. The portion of I-75 included in the study site is a four-lane facility divided by a New Jersey-type median barrier. The shoulders of this facility are curbed, and no shoulder lane is provided. The environmental buildup surrounding this facility is suburban (housing fronts the facility). The illumination system is of the same type as that on I-85. The one interchange in this section is of the diamond type and is signalized.

Dallas, Texas
(See Fig. B-6.)

A. Unlighted Arterial

The unlighted arterial site in Dallas (Fig. B-7) can be broken into three distinct sections, as follows:

1. A four-lane divided highway with a wide curbed median and narrow noncontrasting shoulders, the section is approximately 1 mile in length and is designated as Harry Hines Boulevard (US77). Commercial development is intense along the entire section, but is removed a considerable distance from the edge of the roadway. There are few access driveways; rather, the access is mostly completely open. There are two major intersections (one a traffic circle), and several minor intersections.

2. A four-lane divided highway designated Northwest Highway (Loop 12), with a narrow curbed median and curb and gutter on the outside (Fig. B-8). There is little development along this section, with few access drives; but there are two major intersections and one overpassing structure. Environmental lighting is low except in the area of the two major intersections. The only fixed lighting is safety lighting at the Bachman intersection. This section

PEACHTREE ROAD SOUTHBOUND. FOUR-LANE UNDIVIDED. STAGGERED ILLUMINATION SYSTEM, 400 WATT CLEAR MERCURY VAPOR AT 30 FT; SPACING VARIABLE, MOUNTED ON EXISTING UTILITY POLES.

PEACHTREE ROAD SOUTHBOUND. TYPICAL SECTION, HEAVY ENVIRONMENTAL BUILDUP.

PEACHTREE ROAD SOUTHBOUND. ONE-SIDED ILLUMINATION SYSTEM, 400 WATT CLEAR MERCURY VAPOR AT 30 FT.

PEACHTREE ROAD SOUTHBOUND. ONE-SIDED ILLUMINATION SYSTEM, 400 WATT CLEAR MERCURY VAPOR AT 30 FT. NO SHOULDER, UNEQUAL LANE WIDTH.

Figure B-3. Lighted arterial study section, Atlanta, Ga.

connects with Section 1 at a traffic circle (with safety lighting).

3. A four-lane undivided section approximately 1 mile in length with heavy environmental buildup and critical vertical and horizontal alignment. Shoulders are noncontinuous. Lighting from the development has considerable spill onto the roadway. Pedestrian activity is rather high because of a park located on one side of the facility. There are two major intersections with safety lighting, and several minor intersections. Both major intersections have signal control.

B. Lighted Arterial

The lighted arterial study site (Fig. B-8) can be broken into two distinct sections, as follows:

1. A six-lane divided roadway with narrow curbed median, turn bays at intersections, and curb and gutter on the outside. Much of the approximately 3-mile section has retaining walls. Horizontal alignment is very sharp. Two major intersections and several minor intersections and private drives are involved. The lighting system consists of 1,000-w mercury vapor luminaires mounted at 40 ft and spaced at approximately 240 ft. The average illumination is approximately 2.9 fc; average-to-minimum ratio is 3:1, and maximum-to-minimum ratio is 6:1.

2. A six-lane divided arterial with a one-side lighting system consisting of 400-w mercury vapor units mounted at 30 ft wherever utility poles are located (no set spacing). Although rather meaningless due to the random spacing, the average intensity approximates 0.50 hor. fc. Average-to-minimum ratio approaches 4:1; maximum-to-minimum ratio approaches 10:1.

C. Unlighted Freeway

The unlighted freeway study site (Fig. B-9), designated as US183-114, I-35, John Carpenter Freeway, and Stemmons Expressway, can be broken into the following sections:

1. A six-lane divided facility with a median barrier in

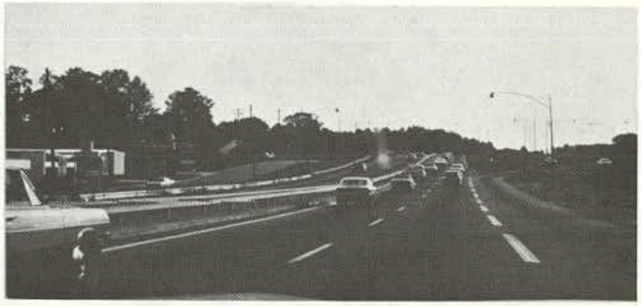
I 85 NORTHBOUND. FOUR-LANE DIVIDED FACILITY. LITTLE ENVIRONMENTAL BUILDUP.

I 85 SOUTHBOUND. TYPICAL SECTION.

I 85 SOUTHBOUND, APPROACH TO SHALLOWFORD ROAD INTERCHANGE. NOTE GUARDRAIL AT SHOULDER.

Figure B-4. Unlighted freeway study section, Atlanta, Ga.

I85 SOUTHBOUND, 4 LANE, DIVIDED FACILITY, NO ENVIRONMENTAL BUILDUP, 400 WATT CLEAR MERCURY VAPOR ILLUMINATION SYSTEM AT 30FT. MOUNTING HEIGHT.



I85 SOUTHBOUND APPROACHING HEAVY ENVIRONMENTAL BUILDUP.

I85 SOUTHBOUND ELEVATED SECTION, STAGGERED ILLUMINATION CONFIGURATION.

I85 SOUTHBOUND TYPICAL SECTION WITH HEAVY ENVIRONMENTAL BUILDUP.

Figure B-5. Lighted freeway study section, Atlanta, Ga.

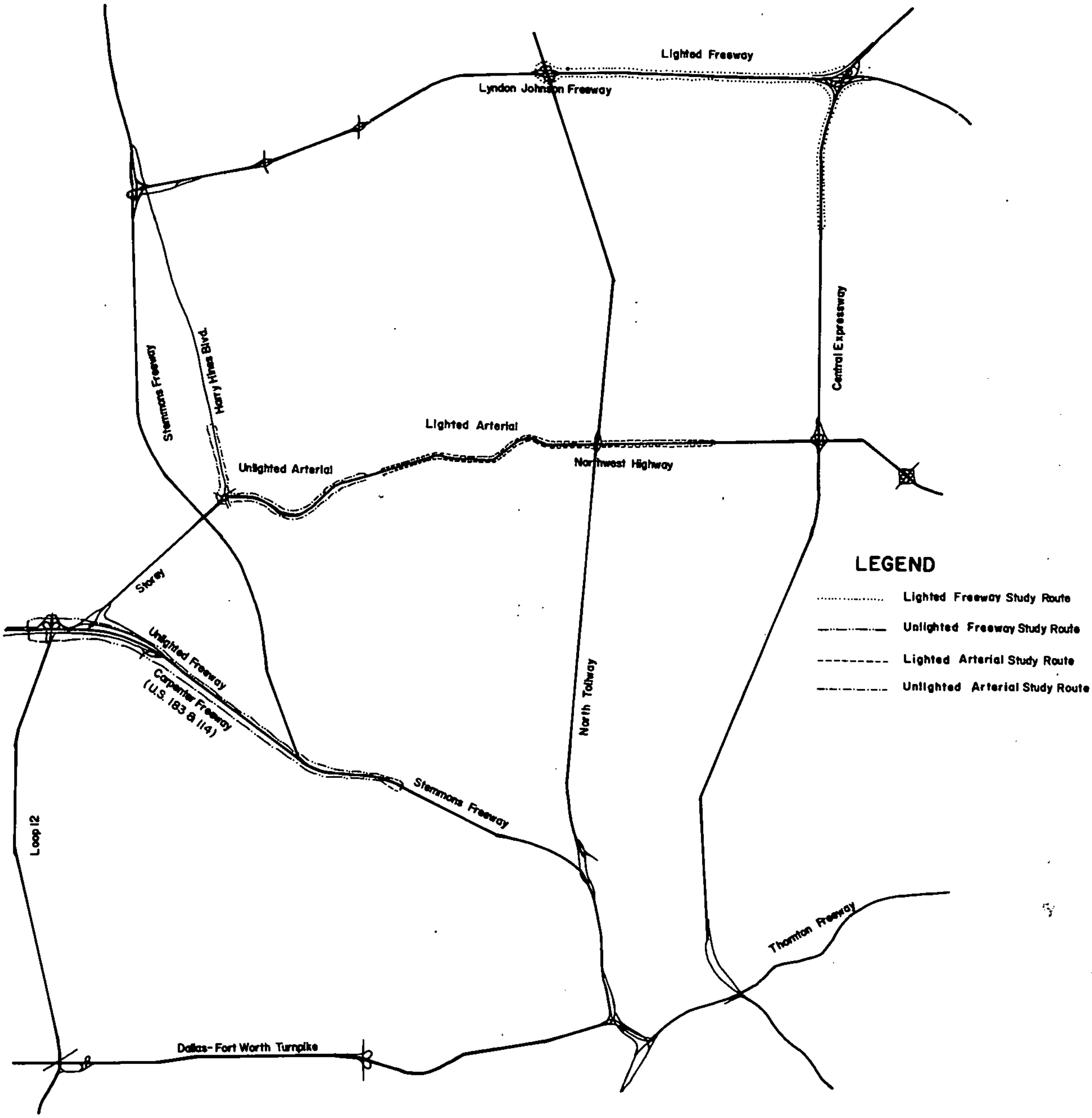


Figure B-6. Location of field study sites, Dallas, Tex.

a 12-ft median. The environmental buildup is heavy, but removed from the facility.

2. A continuation of the first section, with a wide depressed median throughout most of its length. There is virtually no environmental buildup. The section contains three major interchanging areas with no illumination.

3. A short section of I-35 (Stemmons Expressway). The facility is eight-lanes divided with median barrier. Environmental buildup is extremely heavy.

D. Lighted Freeway

The lighted freeway study site involves I-635 (LBJ Freeway), US75 (North Central Expressway), and the interchanging area between the two (Fig. B-10), as follows:

1. An eight-lane divided freeway (I-635) with paved inside and outside shoulders. The section is relatively new. The lighting system consists of 1,000-w mercury vapor units dual-mounted in the median at a height of 50 ft and spaced 280 to 300 ft apart. Average intensity approximates 1.50 hor. fc at an average-to-minimum ratio of 3:1 and maximum-to-minimum ratio of 6:1.

2. A four-lane facility (US75) (North Central Expressway), divided (24-ft median), with an opposite lighting system. The luminaires are 400-w mercury vapor mounted at 30 ft and spaced approximately 200 ft apart. The average intensity approximates 0.80 hor. fc at an average-to-

INTERSECTION OF NORTHWEST HIGHWAY WITH BACHMAN LANE. FOUR-LANE DIVIDED. BEGINNING OF HEAVY ENVIRONMENTAL BUILDUP.

TYPICAL SECTION OF UNLIGHTED PORTION OF NORTHWEST HIGHWAY. SAFETY LIGHTING IN USE AT ALL MAJOR INTERSECTIONS.

Figure B-7. Unlighted arterial study section, Dallas, Tex.

BEGINNING OF ILLUMINATED SECTION, CHANGES FROM 2 LANE UNDIVIDED TO SIX LANE DIVIDED. LIGHTING SYSTEM CLEAR MERCURY VAPOR, 1000 WATT AT 40FT., 250FT. SPACING.

VIEW OF SAME FACILITY, APPROACHING 1ST SIGNALIZED INTERSECTION. VERY LITTLE ENVIRONMENTAL BUILDUP.

TYPICAL SECTION OF NORTHWEST HIGHWAY, GUARDRAILS USED THROUGHOUT; NO SHOULDERS.

ONE SIDED ILLUMINATION SYSTEM, 400 WATT CLEAR MERCURY VAPOR AT 30FT. NO SET SPACING. BEGINNING OF HEAVY ENVIRONMENTAL BUILDUP.

Figure B-8. Lighted arterial study section, Dallas, Tex.

APPROACH TO ELEVATED NORTHBOUND SECTION OF US 183 AND US 114. RELATIVELY HEAVY ENVIRONMENTAL BUILDUP. SIX LANE, DIVIDED.

END OF ELEVATED SECTION APPROACHING WYE OF US 183 AND US 114 NORTHBOUND. LITTLE ENVIRONMENTAL BUILDUP.

WYE OF US 183 AND US 114.

END OF ELEVATED SECTION OF US 183, SOUTHBOUND APPROACHING URBAN AREA. HEAVY ENVIRONMENTAL BUILDUP.

Figure B-9. Unlighted freeway study section, Dallas, Tex.

MERGE OF INWOOD DRIVE ENTRANCE RAMP WITH I 635 EASTBOUND. EIGHT-LANE FACILITY. 1000 WATT CLEAR MERCURY VAPOR SYSTEM AT 50 FT, 250 FT SPACING.

TYPICAL SECTION OF I 635, PAVED SHOULDER, AND CONTINUOUS MEDIAN BARRIER.

US 75 NORTHBOUND, APPROACH INTERCHANGE WITH I 635 FOUR-LANE DIVIDED, WITH NO MEDIAN BARRIER. 400 WATT CLEAR MERCURY VAPOR ILLUMINATION SYSTEM @ 30 FT.

INTERCHANGE OF US 75 WITH I 635 OF PARTIAL CLOVERLEAF TYPE. ILLUMINATED WITH HIGH-MAST SYSTEM.

Figure B-10. Lighted freeway study section, Dallas, Tex.

minimum ratio of 4:1 and maximum-to-minimum ratio of 10.1. Environmental development is heavy.

3. The interchange of I-635 and US75. It is a directional interchange lighted by high-mast lighting. Average intensity is approximately 0.50 hor. fc at an average-to-minimum ratio of 2:1 and maximum-to-minimum ratio of 4:1. Environmental buildup is minor.

STUDY TEAM DESCRIPTION

Atlanta

By using the guidelines discussed previously, the Georgia Division of Highways selected the study team as given in Table B-1.

Dallas

By using the same guidelines, the City of Dallas Transportation Department selected a study team for the Dallas area studies, as given in Table B-2.

QUESTIONNAIRE FORMS

Both the questionnaire on freeways and interchanges and that on collectors and arterials contained the following general instructions:

> The following series of questions concern various features of the traffic facility you have just driven. Please answer each question carefully and check the appropriate blank when indicated. If you do not understand any part of the instructions, please feel free to ask one of the members of the research team for assistance. Your participation is appreciated.

Although the questionnaires for the different types of facility followed the same over-all pattern, the individual questions were tailored to fit the peculiarities of the type of traffic facility, and its lighting category, under study. Specific questions asked on the questionnaires are given in the following.

Freeways and Interchanges

1. How often have you driven this traffic facility? (Check one) __Daily; __Once a week; __Two or three times a year; __Never before.
2. There are several devices that provide the driver with information about the position of his vehicle within a given lane. Read over the following list of these devices and rank them from *most* reliable to *least* reliable as far as you are concerned. (The value 1 should be assigned to the most reliable.)
   __Post-mounted delineators
   __Objects along the roadside
   __Edgelines
   __Lane lines
   __The position of other cars on the roadway
   __Others (please describe)
3. Was there any section of this traffic facility where you were forced to slow down unexpectedly?
   __Yes __No
   (a) If yes, where?
   (b) If yes, what was the reason?
4. Were there any sections of this facility where you thought the roadway went in one direction when in fact it went in another? __Yes __No
   (a) If yes, could this confuse the driver to the point of adversely affecting his safety?

TABLE B-1

MAKE-UP OF ATLANTA STUDY TEAM

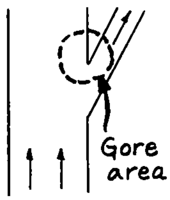
TEAM POSITION	SEX	OCCUPATION	AGENCY	AGE GROUP
Technical	Male	Hwy. engineer	Ga. Div. Hwys.	Mid 30's
Lay driver	Female	Public relations	Ch. of Commerce	Mid 30's
Technical	Male	Lighting engr.	Ga. Div. Hwys.	Early 30's
Lay driver	Male	Draftsman	Ga. Div. Hwys.	Mid 20's
Lay driver	Female	Public relations	Ch. of Commerce	Mid 20's
Technical	Male	Traffic engineer	C. of Atlanta	Early 40's
Administrative	Male	Planning engr.	Ga. Div. Hwys.	Mid 50's
Technical	Male	Psychologist	TTI	Mid 20's

TABLE B-2

MAKE-UP OF DALLAS STUDY TEAM

TEAM POSITION	SEX	OCCUPATION	AGENCY	AGE GROUP
Technical	Male	Traffic engineer	C. of Dallas	Mid 20's
Lay driver	Female	Secretary	C. of Dallas	Early 20's
Technical	Male	Lighting engr.	C. of Dallas	Late 50's
Lay driver	Female	Secretary	C. of Dallas	Early 20's
Technical	Male	Pavement engr.	C. of Dallas	Early 30's
Lay driver	Male	Draftsman	C. of Dallas	Early 20's
Lay driver	Male	Technician	C. of Dallas	Late 20's
Technical	Male	Psychologist	TTI	Mid 20's

5. Do you feel that good visibility of the shoulder is a necessary prerequisite for safe driving when the driver is in:
   (a) The shoulder lane? ___Yes ___No
   (b) Any lane other than the shoulder lane? ___Yes ___No
6. How would you rate the importance of seeing the gore area associated with an exit ramp (see sketch for clarification) if you were:



   (a) In the extreme left-hand lane with no intention of exiting?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
   (b) In the extreme right-hand lane?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
   (c) In the shoulder lane with no intention of exiting?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
   (d) In a left lane with no intention of exiting?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
   (e) In a left lane desiring to exit?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
7. How would you rate the importance of seeing the merge point of an entrance ramp with the freeway if you were:
   (a) In the left lane of the freeway?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
   (b) In the shoulder lane of the freeway?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
   (c) In a middle lane of a freeway?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant; ___Not applicable.
8. How would you rate the importance of detecting changes in the direction of an exit ramp:
   (a) Before you began your exit maneuver?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
   (b) After you were on the exit ramp?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
9. Were you affected in any way by a change in the number of traffic lanes? ___Yes ___No
   (a) If yes, what was this effect?
10. How would you rate the importance of being able to define the edge of the median if you were:
   (a) In the shoulder lane?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
   (b) In the left lane?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
   (c) In a middle lane?
   ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant; ___Not applicable.
11. There are several types of signs currently in use on freeways to convey information to the driver. Rank the following list from *most* important to *least* important when driving on a freeway. (The value 1 should be assigned to the most important.)
   ___Informal signing (location of motel, service station, restaurant, etc.)
   ___Regulatory signs (STOP, SPEED LIMIT 60 MPH, RIGHT LANE MUST EXIT, etc.)
   ___Guide signs (BROWN ST. EXIT ½ MILE, etc.)
   ___Route sign (610 EAST, I-10, etc.)
   ___Warning signs (MERGING TRAFFIC, EXIT SPEED 30 MPH, etc.)
12. Do you feel the order of importance would be the same for an out-of-town driver? ___Yes ___No
   (a) If no, what would be the difference?
13. Were there any locations on this traffic facility where adjacent commercial and/or residential lighting interfered with your ability to see? ___Yes ___No
   (a) If yes, what effect did this lighting have?
14. How would you rate the visibility of *overhead-mounted* signs on this traffic facility? ___Excellent; ___Good; ___Fair; ___Poor; ___Totally inadequate; ___Not applicable.
15. How would you rate the visibility of *roadside-mounted* signs on this traffic facility? ___Excellent; ___Good; ___Fair; ___Poor; ___Totally inadequate; ___Not applicable.
16. (If this roadway is illuminated, skip to question 17.)
   (a) How would you rate the visibility of *overhead-mounted* signs if your headlights were on:
      1. Low beam? ___Excellent; ___Good; ___Fair; ___Poor; ___Totally inadequate; ___Not applicable.
      2. High beam? ___Excellent; ___Good; ___Fair; ___Poor; ___Totally inadequate; ___Not applicable.
   (b) How would you rate the visibility of *roadside-mounted* signs if your headlights were on:
      1. Low beam? ___Excellent; ___Good; ___Fair;

___Poor; ___Totally inadequate; ___Not applicable.

2. High beam? ___Excellent; ___Good; ___Fair; ___Poor; ___Totally inadequate; ___Not applicable.

17. How would you rate the effectiveness of the delineation system on this traffic facility under present illumination conditions? ___Very effective; ___Effective; ___Undecided about effectiveness; ___Ineffective; ___Very ineffective.
18. How would you rate the *legibility* of externally illuminated overhead-mounted signs (if present) vs the visibility of reflective-type signs? (Check one) ___More visible; ___Equal in visibility; ___Less visible; ___Not applicable.
19. Did glare from opposing traffic headlights create a problem? ___Yes ___No
20. Were posted speed limits reasonable under present illumination and traffic conditions? ___Yes ___No Comments:
21. Did it appear to you that there were too many roadside-mounted advertising signs along this traffic facility? ___Yes ___No Comments:
22. How would you rate the importance of the message from advertising signs?
    ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
23. Were the entrances to *on-ramps* clearly visible at an adequate distance? ___Yes ___No ___Not applicable.
    (a) If no, where? Comments:
24. How would you rate the importance of seeing the entrances to *on-ramps* if you were:
    (a) In the left lane with no intention of entering the ramp? ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
    (b) In the shoulder lane intending to use the ramp? ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
    (c) In the shoulder lane with no intention of using the ramp? ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
    (d) In the left lane intending to use the ramp? ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
25. Were you able to see far enough ahead to easily maneuver for entering position? ___Yes ___No Comments:
26. Were the entrances to *off-ramps* clearly visible at a safe distance? ___Yes ___No Comments:
27. How would you rate the importance of seeing the entrances to *off-ramps* if you were:
    (a) In the left lane with no intention of entering the ramp? ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
    (b) In the shoulder (curb) lane intending to use the ramp? ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
    (c) In the shoulder (curb) lane with no intention of using the ramp? ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
    (d) In the left lane intending to use the ramp? ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.

Collectors and Arterials

1. How often have you driven this traffic facility? (Check one) ___Daily; ___Once a week; ___2 or 3 times a year; ___Never before.
2. There are several devices that provide the driver with information about the position of his vehicle within a lane. Read over the following list of these devices and rank them from *most* reliable to *least* reliable as far as you are concerned. (The value 1 should be assigned to the most reliable.)
    ___Post-mounted delineators
    ___Objects along the roadside
    ___Edgelines
    ___Lane lines
    ___The position of other cars on the roadway
    ___Curbs
    ___Others (please describe)
    (a) For the device you ranked No. 1, indicate the reason you chose it.
3. Was there any section of this traffic facility where you were forced to slow down unexpectedly?
    ___Yes ___No
    (a) If yes, where?
    (b) If yes, what was the reason?
4. Were there any sections of this facility where you thought the roadway went in one direction when in fact it went in another? ___Yes ___No
    (a) If yes, could this confuse the driver to the point of adversely affecting his safety?
5. Do you feel that good visibility of the curb or shoulder is a necessary prerequisite for safe driving when the driver is in:
    (a) The extreme right-hand lane? ___Yes ___No
    (b) Any lane other than the extreme right-hand lane? ___Yes ___No
6. Were there any intersecting streets with restricted visibility of traffic on that street? ___Yes ___No
7. How would you rate the importance of seeing intersecting traffic in advance of the actual intersection if:
    (a) They were required to stop and you were not? ___Very important; ___Important; ___Undecided about importance; ___Unimportant; ___Very unimportant.
    (b) You were required to stop and they were not? ___Very important; ___Important; ___Undecided

about importance; __Unimportant; __Very unimportant.

(c) Both of you were required to stop? __Very important; __Important; __Undecided about importance; __Unimportant; __Very unimportant.

(d) Neither of you were required to stop? __Very important; __Important; __Undecided about importance; __Unimportant; __Very unimportant.

8. There are several types of signs currently in use to convey information to the driver. Rank the following list from *most* important to *least* important in terms of the information they present, meeting your needs in driving this facility. (The value 1 should be assigned to the most important type.)
   __Informal signs (location of business, advertisement, etc.)
   __Regulatory signs (SPEED LIMIT 30 MPH, STOP, etc.)
   __Guide signs (BROWN ST., etc.)
   __Route signs (610 EAST, I-10, etc.)
   __Warning signs (CURVE AHEAD, DEAD END, etc.)

9. Do you feel the order of importance would be the same for an out-of-town driver? __Yes __No
   (a) If no, what would be the difference?

10. Were there any locations on this traffic facility where adjacent commercial and/or residential lighting interfered with the driving task? __Yes __No
   (a) If yes, what did you feel was the major effect of this lighting?

11. How would you rate the visibility of *roadside-mounted* signs on this traffic facility? __Excellent; __Good; __Fair; __Poor; __Totally inadequate.

12. (If this roadway is illuminated, skip to question 13.)
   (a) How would you rate the visibility of *roadside-mounted* signs if your headlights were on:
      1. Low beam? __Excellent; __Good; __Fair; __Poor; __Totally inadequate.
      2. High beam? __Excellent; __Good; __Fair; __Poor; __Totally inadequate.

13. How would you rate the effectiveness of the delineation system on this traffic facility under present conditions? __Very effective; __Effective; __Undecided about effectiveness; __Ineffective; __Very ineffective.

14. Did glare from opposing traffic headlights create a problem? __Yes __No

15. Were posted speed limits reasonable under present illumination and traffic conditions? __Yes __No
   Comments:

16. Did it appear to you that there were too many roadside-mounted advertising signs along this traffic facility? __Yes __No Comments:

17. How would you rate the importance of the information on advertising signs? __Very important; __Important; __Undecided about importance; __Unimportant; __Very unimportant.

18. Would you say you were constantly on the alert for pedestrians that might be crossing in the middle of the block? __Yes __No
   (a) If no, did you only look for pedestrians at designated pedestrian crosswalks?

19. Do you feel that illumination of pedestrian crosswalks is a necessary prerequisite for safe pedestrian traffic? __Yes __No; __Not applicable Comments:

APPENDIX C

DRIVER COMFORT QUESTIONNAIRE

QUESTIONNAIRE DESIGN

The final choice of a questionnaire design and scaling method was based on several criteria, among which were:

1. The ability to distinguish between different levels of driver comfort and/or discomfort as a function of illumination.
2. Provide an indication of whether discomfort was a function of:
   (a) Geometric conditions.
   (b) Driving task demands.
   (c) Poor visibility.
   (d) General anxiety.
3. Based on objectively derivable measures of effect.
4. Ability to apply appropriate statistical analysis.
5. Ease of administration and scoring.

The design finally chosen was based on a questionnaire originally conceived by Perchonok and Hurst,* and many of the "questions" developed by these authors were used in the construction of this questionnaire.

However, a different scaling technique was chosen.

QUESTIONNAIRE CONSTRUCTION

The questionnaire consisted of 24 statements: seven were concerned with general apprehension, seven with visually

* Perchonok, K., and Hurst, P. M., "Effects of Illumination on Operating Characteristics of Freeways. Part IV. Driver Apprehension." *NCHRP Report 60* (1968) pp. 93-105.

induced discomfort, five with geometry-induced discomfort, and five with driving task discomfort. Under each statement appeared the following scale:

Strongly Agree 1 2 3 4 5 6 7 Strongly Disagree

The respondent's task in each case was to circle the number that most closely expressed his feelings about the statement. The score for an individual was the sum of his item scores. By using a scale of this type, any total score less than 74 would indicate a relatively comfortable state, whereas total scores greater than 74 would indicate a relatively uncomfortable state.

Subjects

A total of 15 respondents filled out the questionnaire. They were the same subjects used in conjunction with the field studies discussed in Appendix B. Every attempt was made to include a cross section of the driving public.

Procedure

On the basis of previously determined criteria, two basic types of traffic facilities were selected as study sites. These consisted of an illuminated and a nonilluminated arterial, and an illuminated and a nonilluminated freeway, making four study sites in all. In each situation, two subjects and a member of the research team drove through the study site, with one subject serving as an observer and one subject driving. After the route had been traversed, the two subjects switched places so that the first observer drove while the first driver was given an opportunity to observe. The purpose of the research team member in all cases was to record the comments made by the subjects, to stimulate conversation, and to give verbal instructions as to the route to be driven. Immediately upon completion of the study route drive, the subjects were administered the questionnaire. No conversation was allowed among the subjects until the questionnaire was completed. This procedure was repeated until all study sites had been driven and observed by each subject.

QUESTIONNAIRE FORM

The questionnaire contained identifier items such as the route designation of the study site, the location of the study site, the subject's name, and the date of administering the questionnaire. Also included were general instructions, as follows:

> This questionnaire concerns driving comfort under nighttime driving conditions. Please read each statement carefully and then circle the number on the scale that is indicative of your feelings about the statement. For example, if you *strongly agree* with the statement: "The glare from the opposing car's headlights was so bright it hurt my eyes," you would circle the 1 on the scale. If you *strongly disagree* with this statement, you would circle the 7. If you were only in *slight disagreement,* you might want to circle the 5. The important thing to remember is that the end points of the scale represent the extreme attitudes toward the statement, and the numbers between 1 and 7 represent lesser degrees of agreement or disagreement with the statement. It is important that you respond to all statements. If there is any statement about which you are undecided, circle the 4 to indicate that you are undecided.
>
> If you have any questions, or cannot understand one of the statements, please ask a member of the research team for assistance. Your participation is appreciated.
>
> *Example:*
>
> The glare from the opposing car's headlights was so bright it hurt my eyes.
>
> STRONGLY AGREE 1 ② 3 4 5 6 7 STRONGLY DISAGREE
>
> Indication of rather strong agreement. *Do not circle the descriptors.*

"Questions"

1. There were times when I could not determine the direction of the road ahead.
2. I did not feel that it was necessary to concentrate to an unusual degree on the driving task.
3. I drove much more carefully than I would during the daytime.
4. I felt slightly apprehensive at times.
5. It did not bother me when the view of the roadway was blocked by an overpass or other object.
6. There were times when I could not see everything I desired.
7. I would not like to drive on this road at night any more than necessary.
8. For the most part, I felt no great demands on my driving ability.
9. Actually, the driving was not an easy task.
10. I always felt confident that I was safe.
11. Much of my driving consisted of rather automatic responses.
12. There were times when I experienced some difficulty seeing the edge of the road.
13. I was not bothered to any appreciable degree by glare from oncoming cars' headlights.
14. Lights from commercial establishments along the roadway definitely bothered me.
15. I would not have felt comfortable driving with my headlights on low beam only.
16. The transition from one type of traffic facility to another (for example, from a freeway to a city street) was at times difficult to make.
17. In actuality, it required all my concentration just to maintain good lane position.
18. There were times when I experienced some difficulty seeing the edge of the road.
19. I did not feel that the drive was particularly stressful.
20. There were times when I just did not feel I could see far enough ahead.
21. I was never surprised by sudden changes in direction of the roadway.
22. There were several instances where I thought some risk was involved when making a maneuver.
23. At no time did I actually feel uncomfortable while driving through this facility.
24. Driving on this facility at night is more comfortable than driving it during the daytime.

TABLE C-1

DRIVER COMFORT SCALE, RAW SCORES

SUBJECT	UNLIGHTED ARTERIAL	LIGHTED ARTERIAL	UNLIGHTED FREEWAY	LIGHTED FREEWAY
1	84	46	99	51
2	95	136	139	98
3	99	27	153	32
4	77	110	122	103
5	87	64	107	50
6	66	53	133	53
7	89	86	146	88
8	86	58	102	63
9	92	73	109	86
10	84	42	83	56
11	75	56	74	57
12	80	67	102	87
13	86	46	91	56
14	97	74	113	99
15	74	39	45	38
Total	1271	977	1618	1017
Mean	84.73	65.13	107.87	67.80

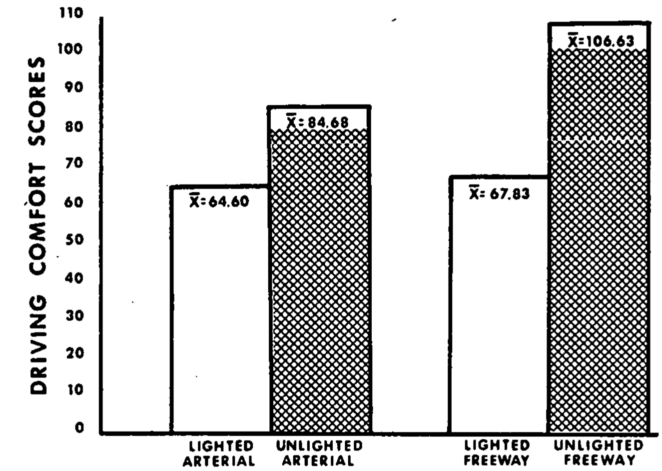


Figure C-1. Mean driving comfort scores.

QUESTIONNAIRE RESULTS

The raw (total) scores for each of the 15 subjects on each type of facility are presented in Table C-1. A Mann-Whitney U test was applied to these data; the results are given in Table C-2. As can be seen, the difference between illuminated and nonilluminated conditions is significant at the 0.01 level on both arterials and freeways. This indicates that the driver is more comfortable under illuminated conditions. Figure C-1 illustrates this finding. In addition, it shows that although illuminated arterials do not differ greatly from illuminated freeways with regard to driver comfort, nonilluminated freeways are much more uncomfortable to drive than nonilluminated arterials.

Total scores for four general types of discomfort inducers (geometric conditions, driving task demands, poor visibility, general anxiety) are presented in Table C-3. The effect of illumination on the degree of comfort or discomfort manifested by a given type of inducer for a given type of facility was determined by comparing the amount of discomfort produced by each type of inducer for illuminated vs nonilluminated situations (Table C-4). The statistical analysis procedure employed was the Mann-Whitney U test. As evidenced by Table C-4, the discomforting effect for all four types of discomfort inducers was less under illuminated conditions. An analysis of the data indicated there were no significant differences in the degree of discomfort manifested by the different inducers.

The finding that the driver is more comfortable under illuminated conditions is in line with other research findings in this area. The interesting point is that the mean scores for the illuminated conditions indicate that the driver is actually comfortable when operating on an illuminated traffic facility, rather than just less uncomfortable than he would be when driving on a nonilluminated traffic facility. As discussed earlier, a mean score of 74 represents the borderline between comfort and discomfort. From Figure C-1 it is evident that the mean score for each of the illuminated conditions is well below this value, and the mean score for each nonilluminated condition is significantly above this value. It is also apparent from Figure C-1 that although the driver is just as comfortable on an illuminated arterial as he is on an illuminated freeway, he is extremely more uncomfortable on nonilluminated freeways. This difference in degree indicates that the illumination of freeways would have a greater effect on the comfort state of the driver than would the illumination of arterials. Scores were reduced from an average of 106.63 for nonilluminated freeways to 67.83 for lighted freeways, whereas scores were reduced from 84.68 for nonilluminated arterials to 64.60 for illuminated arterials. This difference in the effect of

TABLE C-2

COMPARISON OF DRIVER COMFORT SCORES ON ILLUMINATED AND NONILLUMINATED FACILITIES

CONDITION	ΣR_i LARGER	ΣR_i SMALLER	N_1	U	T SIGNIFICANCE LEVEL
Illuminated vs nonilluminated arterials	293.5[a]	157.5	15	171	$p < 0.01$
Illuminated vs nonilluminated freeways	373.5[a]	151.5	15	171	$p < 0.01$

[a] Nonilluminated condition.

TABLE C-3

RAW SCORES FOR DISCOMFORT INDUCERS [a]

	UNLIGHTED ARTERIALS				LIGHTED ARTERIALS				UNLIGHTED FREEWAYS				LIGHTED FREEWAYS			
	GI [b]	GA [c]	DT [d]	V [e]	GI [b]	GA [c]	DT [d]	V [e]	GI [b]	GA [c]	DT [d]	V [e]	GI [b]	GA [c]	DT [d]	V [e]
	79	79	72	97	36	57	29	52	71	83	68	89	36	55	39	61
	72	78	65	92	51	43	28	51	58	75	59	75	56	48	36	41
	71	81	63	69	42	36	32	35	81	73	65	55	50	39	31	38
	65	65	33	76	40	32	33	51	67	55	46	49	43	32	29	32
	61	58	64	50	37	28	29	32	70	51	52	55	46	27	32	29
		68		91		36		52		71		76		47		37
		96		88		78		37		101		74		82		51
Σ	348	525	297	563	206	310	151	310	347	509	290	473	231	330	167	289
Mean	69.60	75.00	59.40	80.43	41.20	44.28	30.20	44.28	69.40	72.71	58.00	67.57	46.20	47.14	33.40	41.28

[a] Total score for each question for all subjects.
[b] Geometry-induced discomfort.
[c] General anxiety.
[d] Driving task discomfort.
[e] Visually induced discomfort.

TABLE C-4

EFFECT OF ILLUMINATION ON THE LEVEL OF DISCOMFORT AS A FUNCTION OF FOUR INDUCERS

	ARTERIALS					FREEWAYS				
	ΣR_i					ΣR_i				
CONDITION	LARGER	SMALLER	N	U	T PROB.	LARGER	SMALLER	N	U	T PROB.
Geometry-induced discomfort	147.5 [a]	62.5	10	71	$p < 0.01$	140.5 [a]	69.5	10	71	$p < 0.01$
Driving task discomfort	147.0 [a]	63.0	10	71	$p < 0.01$	146.5 [a]	63.5	10	71	$p < 0.01$
General apprehension	282.5 [a]	123.5	28	147	$p < 0.01$	267.5 [a]	116.9	20	147	$p < 0.01$
Visually induced discomfort	290.0 [a]	116.0	28	147	$p < 0.01$	227.0 [a]	129.0	20	147	$p < 0.01$

[a] Nonilluminated condition.

illumination indicates that, on a priority basis, freeways should be illuminated before arterials.

It is possible that the large amount of discomfort on the nonilluminated freeways examined in this study is primarily a function of the relatively high speeds attained on this type of facility. This increase in vehicle speed would place an increased load on the amount of time required by the driver to make decisions related to driving task demands, changes in geometry, and, in essence, any response the driver would be required to make. Thus, the driver would be required to make course corrections, as well as other maneuvers, quicker than normal as a function of his increased speed and reduced vision under nonilluminated conditions. This situation would not be as critical for nonilluminated arterials because speed is comparatively slow, thus less demand would be placed on the driver in terms of required response time.

It was hoped that the questionnaire would provide information allowing for the specification for a hierarchy of discomfort inducers as a function of different types of traffic facilities, but, as previously indicated, no specification of this nature could be made.

APPENDIX D

WARRANTING FIXED ROADWAY LIGHTING FROM A CONSIDERATION OF DRIVER INFORMATION NEEDS

It was desired in the research effort to investigate the possibility of using a vision model for warranting roadway lighting. This appendix describes the limited effort in this regard. Although the concept has considerable potential and should be investigated further, limitations of time and funds precluded further action in this project.

WARRANT APPROACH

Fixed roadway lighting has many beneficial aspects. It improves roadway visibility and traffic operations, improves the criminal surveillance capabilities of the police, and may express the attitudes of the community. The relative benefits of fixed roadway lighting depend, then, on the objectives and values of the group in question. The premise of the warrant system presented here is that fixed roadway lighting is installed, where warranted, to increase the level of service afforded motorists at night to an acceptable level that is commensurate with safe and efficient traffic operations.

Installation of fixed roadway lighting in accordance with accepted design practices would almost never result in negative net benefits to the motoring public if someone else were paying for the costs of installation and operation. Thus, if some other governmental agency finds that fixed roadway lighting should be installed, based on its own socio, economic, or political considerations, installation of fixed roadway lighting should be permitted, even encouraged. However, the agency that finds that roadway lighting is needed to fulfill its objectives should be responsible for funding the installation and operations of the project. In the least, the distribution of costs to be charged various agencies should be made at a high administrative level and should not be the concern of the highway lighting engineer, whose primary concern should be in determining the motoring public's need for fixed roadway lighting.

The second premise of this warrant system is that traffic safety is a by-product of efficiency of traffic operations. Therefore, this warrant system is designed to evaluate whether efficient and effective vehicle control is probable within a given night driving environment. It is structured toward evaluating the problem causes rather than reacting to symptoms of the problem. It seeks to create a satisfactory night driving environment in which to perform the required driving tasks in an efficient manner rather than evaluating fatality statistics which may provide little guidance as to the probable causes.

In developing requirements for a suitable visual night driving environment for providing safe and efficient traffic operations, it is first necessary to provide a general definition of "suitable visual night driving environment." The key to this definition is contained within the framework of the roadway-driver-vehicle complex. Inasmuch as vision holds the veto power over the entire complex, there must be a reservoir of visual information available to the driver so that he may accomplish the driving task in operating a vehicle from one point to another. The following general definition has been adopted for the presentation of this research:

> Suitable Visual Night Driving Environment—An environment in which there is readily available the visual information necessary for a given driving population to safely and efficiently perform the driving tasks under the prevailing night driving conditions.

DRIVING TASKS

There are three basic levels in the driving tasks: (1) positional level, (2) situational level, and (3) navigational level. These levels have been ordered into a hierarchy that describes the manner in which a driver would behave if he became overloaded by the demands of the driving task. In an overloaded situation, the driver would "load-shed" higher-level tasks until an acceptable task load is reached. The information needs and priorities associated with each level are summarized as follows:

1. Positional level—lowest in the hierarchy; must always be satisfied before other levels can be attended to. Consists primarily of routine speed and lane position control.
2. Situational level—second in the hierarchy; must be satisfied before third level is attended to, but not before positional level is satisfied. Consists of change in speed, direction of travel, or position on the roadway as a result of a change in the geometric, operational, and/or environmental situation.
3. Navigational level—third in the hierarchy; performed only if levels 1 and 2 are satisfied. Consists of selecting and following a route from the origin to the destination of a trip.

Field study teams composed of lay and professional drivers were formed and driving task studies were conducted and analyzed to determine the cause or nature of conditions, situations, or problems found during the performance of the driving task at night. Most night driving problems were found to be related to problems associated with the driver's obtaining the information needed to safely and efficiently perform the driving task.

The first consensus reached by the study team involved the positional information level. All team members stressed the necessity of positional information at all times. This information (in the form of lane lines, edgelines, and curb delineation) was considered to be the most critical and most needed information because it held the key to other informational levels. All other tasks at the situational and navigational level depended on the sufficiency of these visual inputs. The subjects were insistent that more orderly consideration and accomplishment of the situational and navigational tasks is possible when positional information is readily available.

Another consensus reached by the study teams involved operations on the various traffic facilities. Higher speeds and higher volumes were definitely considered to be producers of visual task problems. First, it was agreed that opposing headlights introduced periods when vision was virtually obliterated and that the problem increased as the number of opposing vehicles increased. Lateral separation of vehicles and fixed lighting, especially median-mounted, were considered the best solutions to the problems. It was also agreed that all driving task accomplishments became more difficult as volumes and speeds increased, mainly because of the competition involved between the various informational needs.

Provision of a Suitable Visual Night Driving Environment

Provision of a suitable visual night driving environment requires that a given driving population should always be able to perform all three levels of the driving task within a time frame such that safety and efficiency are not reduced. An environment that causes the driver to load-shed certain driving tasks and information needs could not be considered a suitable night driving environment. To safely and efficiently perform the driving task, a driver must be able to perform navigational and situational tasks as well as positional control tasks.

Load-shedding by a driver results when the information processing and vehicle control demands exceed the capabilities of the driver to service and perform them. It is not specifically the amount of work that the driver is required to perform in satisfying the driving task that results in load-shedding, but rather the rate at which the work load must be accomplished.

The rate at which the driver must be capable of performing depends on the information needed to safely and efficiently perform the various driving tasks, the time required to obtain the information, and the time available to obtain the information. The information needs can be related to the positional, situational, and navigational levels of the driving tasks. Whereas positional information is immediately used to implement a steering or speed control action, most situational and navigational information tasks require only information processing or scanning actions on the part of the driver, with few overt control responses necessary. More situational information is needed as the complexity of the driving environment increases; also, navigational tasks increase as the number of alternate routes increases.

For a given operational and geometric situation, the drivers' information demands are fixed, with only the information supply in time a variable. The information supply in time depends on the length of roadway visible and varies inversely with the speed of the driver. The faster the motorist drives, the less the information supply. Fixed roadway lighting is one design variable that not only improves the information processing capabilities of the driver, but also increases the supply of information available to the motorist by making a longer section of roadway visible to him. This increase in the supply of information available to the motorist reduces the rate at which driving work tasks must be done, thereby diminishing the possibilities of load-shedding, which results in a more suitable night driving environment.

Warranting Criterion

Thus, this model of night driver behavior is presented with the objectives of showing why fixed roadway lighting is warranted to provide for safe and efficient vehicle control and under what conditions this occurs. The basic criterion used for evaluating whether fixed roadway lighting is warranted is whether the model indicates that a suitable night driving environment is provided. For this model, a suitable night driving environment is defined as one that enables the driver to perform all three levels of the driving task without having to load-shed any of them. Load-shedding is assumed to occur when the information demands exceed the information supply.

The Design Driving Tasks

The driver is assumed to be driving on a roadway that does not have fixed roadway lighting. Information workload demands for varying traffic conditions will be compared to the information supply provided without fixed roadway lighting to determine if the information supply is adequate. If the information supply is not adequate, as indicated by the demand exceeding the supply, fixed roadway lighting is warranted.

The design driving tasks and the sequence in which the driver is assumed to service the information needs follow a cyclic order, as dictated by the primacy concept, and are as follows:

1. Positional information search and control.
2. Situational information search.
3. Navigational information search.
4. Positional information search and control.
5. Etc.

The basic premise of this model is that safe and effective positional control of the vehicle can be maintained only if the driver can obtain redundant positional information of the roadway ahead each time he returns to the positional information search and control level. After the driver completes a positional task, he is assumed to be traveling without additional positional information while he is performing situational and navigational information searches and until he returns and completes the following positional information search update. From a satisfactory design viewpoint, the driver should not be required to "fly blind" into a section of roadway he has never seen before. In this model, therefore, the driver must obtain positional information on the roadway ahead while he is still on a section previously evaluated during the last positional update.

Computation of Information Demand and Supply

The information demand will be the time required to fulfill a sequence of positional, situational, navigational, and redundant positional information searches. That is, the demand is

$$D = \Sigma(P_i + S_i + N_i + P_{i+1}) \qquad \text{(D-1)}$$

in which

D = the information demand on a section of roadway, in seconds;
P_i = the time required to obtain positional information on cycle i;
S_i = the time required to obtain situational information on cycle i;
N_i = the time required to obtain navigational information on cycle i; and
P_{i+1} = the next required positional information search update on cycle $_{i+1}$, which must be achieved within the section of roadway visible during P_i.

This model attempts to quantify the information demands arising from different geometric, operational, and environmental situations.

The information supply is given by

$$C = \frac{\overline{L}}{1.47V_r} \qquad \text{(D-2)}$$

in which

C = information supply, in seconds;
$\overline{L}$ = average visible length of roadway ahead without fixed roadway lighting, in feet; and
V_r = running speed of vehicle, in miles per hour.

Eq. D-2 shows that the information supply, in seconds, increases with the installation of fixed roadway lighting, because $\overline{L}$ would increase appreciably, and decreases with increasing speeds.

To summarize, when the information demand, D, exceeds the information supply, C, on a section of unlighted roadway, a suitable night driving environment has not been provided and fixed roadway lighting is warranted. If the demand, D, is divided by the supply, C, forming an information index ratio, I, roadway lighting is warranted when

$$I = \frac{1.47D\,V}{\overline{L}} = >1 \qquad \text{(D-3)}$$

Positional Information Needs

The field studies of this research effort have revealed that most of the positional information is obtained at night from lane lines, edge lines, curb lines, position of other vehicles, and a general view of the roadway. During good viewing conditions, the driver may usually obtain positional information with peripheral vision. However, Gordon (*1*) and Rockwell et al. (*2*) have shown with eye mark studies that under night driving conditions visual fixations of edge, curb, the roadway ahead, and shoulder lines are made more frequently, presumably to obtain positional information.

In general, the time required for the visual perception of an information source to occur is composed of latency, movement, and fixation times (*3*). Latency is the delay between the time the stimulus is presented and the time the eyes begin to move. Normally, the latency time averages about 0.2 seconds. The stimulus in this model is not a light or object but a continuous objective of searching for information to satisfy driving task needs. Thus, no latency time is assumed to exist in this model.

The time required for eye movement only varies between 0.029 and 0.10 sec for movements of 5 to 40 deg, respectively (*3*). A movement time of 0.05 sec was assumed due to the relatively small angular movements required.

After the eye has moved to the object, the eye must fix on it. The mean fixation time for observing road and lane markers was found by Mourant, Rockwell, and Rackoff (*4*) to be 0.28 sec. Luckeish and Moss (*5*) observed in the laboratory a mean fixation pause of 0.17 sec, with a range of 0.1 to 0.3 sec. It is believed that the Mourant data more accurately reflect the positional information demand,

$$P_i = 0.3\left(\frac{D^\circ}{2} + 1\right)\left(\frac{5}{W - 7}\right) \qquad \text{(D-4)}$$

in which

P_i = positional information demand, in seconds;
D° = average degree of horizontal curvature; and
W = average lane width, in feet.

Because the driver is obtaining redundant positional information, it is assumed that only small steering control corrections would be necessary. To implement these small control corrections, a minimal amount of cognitive and physical effort would be required by the driver, thus permitting him to implement the physical control correction while he begins to search for his situational information needs. Therefore, no additional time would be required to effect a positional information search and control update.

Situational Information Search

Situational information needs arise due to changes in the geometric, operational, or environmental situation. Because the driver does not know when an actual hazard may occur, he is on the lookout for the possibility where he perceives hazardous areas to exist. The eye mark studies (*1, 2*) have shown that the driver believes that the roadway ahead is always a potentially hazardous area. The potential always exists that a stopped vehicle or an object may be in the lane ahead. The roadway ahead also offers the first clue to geometric changes.

Areas that may generate traffic movements that potentially conflict with the driver's desired path are also searched for situational information by the driver. Rockwells' eye mark studies, even with a small sample, indicate that the drivers scan more potentially hazardous areas as they increase in number (*2*). In the model presented here, these situational areas have been classified into (1) intersectional friction, (2) internal friction, (3) medial friction, and (4) marginal friction. These four types of hazards may arise on one or both sides of the driver in some cases, requiring two eye movements. To ensure safe and efficient operation, the driver is assumed to be required to scan these areas if a potential hazard is present a certain percentage of the time.

Intersectional Friction

Intersectional friction, as used here, may be caused by vehicles on a connecting facility approaching, desiring to enter, or crossing the driver's roadway. Normal at-grade intersections may produce potentially hazardous areas on both sides, depending on the level of traffic volumes and exposure times of the conflicting traffic. Freeways are subject to intersectional friction at ramps and connecting roadways. In addition, at interchanges the crossing roadway may also cause intersectional scanning to occur due to the distracting influence of vehicles crossing the through facility at night. (Drivers' eyes are involuntarily attracted to the movement of lights at night.)

The following analysis is presented to provide a basis for determining whether an intersection or ramp might experience night intersectional friction due to cross traffic. It is assumed that the driver will scan one approach if vehicles are detectable on the average at least 25 percent of the time and will scan both sides, if possible, when vehicles are detectable at least 50 percent of the time.

It is assumed that a vehicle would be noticeable as it approaches the intersection at night if it is within 200 ft of the intersection. This implies that either the vehicle or its low-beam headlights would be visible. Using a comfortable deceleration rate of 5 fpsps and an initial approach speed of 35 mph, the crossing vehicle would be noticeable for 10 seconds before it stops at the intersection.

The average delay the crossing vehicle experiences before entering the intersection is assumed to be 5 sec. This value is thought to be reasonable for stop- and yield-controlled approaches and is not an unreasonable value for signalized intersections at night where the average delay is about one-eighth cycle.

Allowing a 3-sec interference time for crossing or entering yields a total of 18 sec that the crossing vehicle would be noticeable or distracting to the driver. Thus, the minimum total cross-street intersection volumes to meet the one-side criterion is $q = \frac{3{,}600 \times 25\%}{18 \text{ sec}} = 50$ vph. For both sides to warrant 25 percent of the time, each side is required to occur at a 50 percent rate; thus, the volume required to warrant both sides would be $q = \frac{3{,}600 \times 50\%}{18 \text{ sec}} =$ 100 vph. These night volumes will be converted to average daily traffic by applying a *K*-factor, the ratio of the night design hourly volume to the 24-hour average daily traffic of 5 percent (*6*) to generalize and simplify the warranting analysis. The resulting equivalent average daily traffic is 1,000 vpd one side warrant, and 2,000 vpd both sides warrant, where possible (see Table D-1).

As noted previously, the traffic flowing on the roadway crossing a freeway may cause intersectional friction due to the involuntary attraction of the drivers' eyes to the moving lights on the crossing facility. It is assumed that the traffic on the crossing facility would be visible for 400 ft, or 200 ft on each side of the driver. The crossing traffic is assumed to be traveling at 40 mph. Thus, on each side of the driver, each crossing vehicle would be visible for 3.41 sec. Again, assuming an average minimum exposure rate of 25 percent of the time for one side distraction, or a 50 percent rate for both sides occurring simultaneously, and a *K*-factor of 5 percent, the minimum average daily traffic volumes to warrant one- and two-sided intersectional friction for interchanges are $Q = \frac{3{,}600 \times 25\%}{3.41 \text{ sec} \times 0.05} = 5{,}300$ (one side) and $Q = \frac{3{,}600 \times 50\%}{3.41 \times 0.05} = 10{,}600$ (both sides). Working values of 5,000 and 10,000 vehicles per day are recommended.

Intersectional friction may also be caused by traffic desiring to turn left at an intersection from the roadway being evaluated. The distraction time to other vehicles caused by the left-turning vehicle would be approximately 18 sec (10 sec slowing to a stop, 5 sec average stop delay, and 3 sec to cross as before). Thus, the minimum total left-turning volume per hour from the roadway of interest to meet the 25 percent time criterion would be $q = \frac{3{,}600 \times 25\%}{18 \text{ sec}} = 50$ vph.

For a section of roadway to be considered to have intersectional friction from the driver's viewpoint, the intersection should be visible and the intersectional activity previously discussed would have to fall initially in the driver's peripheral field of view. Under these considerations, intersectional friction is assumed to affect a 500-ft section of approaching roadway.

For a continuous section of roadway to cause any consistent increase in the driver's situational information work load, the roadway will frequently have to have the type of situational activity being considered. Here the activity is intersectional friction. For the continuous warranting of intersectional friction scan areas, a minimum of two warranting intersections per mile is recommended. Because freeway interchanges affect a larger area, the continuous warranting of intersectional friction would require one warranting interchange every 1½ miles.

Internal Friction

Internal traffic friction may arise on either side of the driver due to the possibility and act of improper lane changing by other motorists traveling in the same direction of flow. The number of lanes, type of traffic flow, and traffic volumes are the important determinants in evaluating the probabilities for improper lane changing. Roadways with four or more lanes could have internal traffic friction on one side and facilities with six or more lanes could have internal friction on both sides. Consideration of oncoming traffic is handled as medial friction with respect to the assumed direction of flow.

With the objective of quantifying the likelihood that a motorist would scan the traffic on one or both sides of his vehicle for possible hazardous lane-changing maneuvers into his lane, the following analyses are presented. Two types of traffic flow conditions are considered: continuous

TABLE D-1

EVALUATION OF A ROADWAY'S SITUATIONAL INFORMATION DEMANDS

SITUATIONAL INFORMATION SOURCE	TYPE OF FACILITY	WARRANT VOLUME (MIN ADT) ONE SIDE	BOTH SIDES	GUIDELINES	NUMBER OF WARRANTING SITUATIONAL SCAN AREAS
A. Intersectional friction	1. Freeways	1,000	—	For continuous warrant, at least one warranting entrance ramp per mile.	____
	2. Streets and highways	1,000 [a] 50 [a, b]	2,000 [a] —	Total cross-roadway approach volumes. [a] Minimum of two warranting intersections per mile for continuous warranting conditions. [b] Total roadway's left-turning vehicles per peak night hour at intersection.	____
	3. Interchanges	5,000	10,000	Total cross-roadway traffic. For continuous warranting, at least one warranting interchange every 1½ miles.	____
B. Internal traffic friction	1. Freeways: (a) 4 lane (b) 6 lane (c) 8 lane (d) 10 lane	 20,000 30,000 40,000 50,000	 — 57,000 76,000 95,000		____
	2. Streets (a) 4 lane (b) 6 lane (c) 8 lane	 5,000 5,000 5,000	 — 9,000 9,000		____
C. Medial friction	1. Undivided facilities: (a) Unsignalized (b) Signalized	 5,000 4,000	 — —		____
	2. Median divider 30 ft	10,000	—		____
	3. Median type	Curbed or discontinuous			
D. Marginal friction	1. Driveways and minor intersections	30 [c]	60 [c]	Vehicles per peak night hour per 500 ft of roadway. (Divide minor intersection volumes by 3.0 before adding.) [c] At least two warranting 500-ft sections per mile for continuous warranting.	____
	2. Curb parking or bus stops	Any [c, d]	Any [c, d]	[d] On near side only for divided facilities.	____
	3. Pedestrians	Noticeable [c, d]	Noticeable [c, d]		____
	4. Two-way frontage roads	5,000 [c, e]		[e] Average daily traffic on two-way frontage road.	____
E. Roadway ahead	1. All	0	—		1
F. Traffic signals	1. All	Present [f]	—	[f] At least two signals, STOP signs or YIELD signs per mile on the roadway for continuous warranting	____
	Sum=			Total number of warranting situational scan areas.	____

Total situational scan time, $S_t = 0.35 \times \text{Sum} =$ ________ sec or freeway flow, and interrupted or signalized flow. For continuous flow, the traffic stream tends to be more uniformly distributed over a long section of roadway, whereas for signalized conditions the signals produce groups of vehicles confined in queues of a much higher density than continuous-flow volumes would indicate.

In continuous or freeway flow, the driver is assumed to be concerned with a short section ahead on the adjacent lanes from which possible hazardous or situational lane changes would occur. This distance was established, based on the premise that a driver will not be concerned with lane-changing maneuvers into his lane that might occur far enough ahead that they would not require him to apply his brakes. That is, any necessary deceleration due to a lane change beyond the selected distance could be accomplished by simply releasing the accelerator.

The average speed change required by the speed differential between the lane-changing vehicle and the driver's vehicle was assumed to be 5 mph. This speed differential is representative of the average standard deviation of vehicle speeds (*7*, p. 66). Over the speed range of 30 to 70 mph, a 5-mph speed change can be achieved without braking in about 200 ft (*7*, p. 26). Thus, if a vehicle occupies an adjacent lane within 200 ft ahead, the driver would scan these vehicles to determine if there were any indications of impending lane changing.

A uniform distribution of space headways of vehicles is assumed for simplicity, and a minimum exposure rate to potential lane changing of 25 percent of the time, equivalent to space for continuous flow, to warrant a one-side scan area, is assumed. To warrant simultaneous scan areas on both sides at the 25 percent level requires that each side have an exposure rate of at least 50 percent. The minimum lane densities in vehicles per lane-mile to meet the criteria are $k = \frac{5{,}280 \times 25\%}{200 \text{ ft}} = 6.6$ vplm (one side), and $k = \frac{5{,}280 \times 50\%}{200 \text{ ft}} = 13.2$ vplm (both sides).

For continuous traffic flow conditions, these lane densities can be converted into equivalent traffic volumes by using Greenshield's well-known model of traffic flow (*8*)

$$q = u_f\, k - \frac{u_f}{k_j}\, k^2 \qquad \text{(D-5)}$$

in which

q = minimum lane volume, in vehicles per hour;
k = minimum computed lane density, in vehicles per lane-mile;
u_f = free speed of the traffic stream; and
k_j = jam density of the traffic stream.

By letting $u_f = 60$ mph and $k_j = 130$ vplm (*8*), substitution of the computed warranting densities of 6.6 and 13.2 vplm yields equivalent warranting lane volumes of 375 and 710 vph in the warranting lanes. For generalized comparative purposes, all night volumes are converted to total two-way average daily traffic. A directional distribution of 60/40 and a *K*-factor (ratio of night volume per hour to average daily traffic) of 0.05 (*6*) are assumed. Lane distribution factors of 1.25 are assumed to exist in the critical lanes. The resulting two-way average daily traffic to warrant one-side and both-sides internal traffic friction on freeways would be

WARRANTING AVERAGE DAILY TRAFFIC FOR FREEWAYS

NO. OF FREEWAY LANES	ADT FOR INTERNAL TRAFFIC FRICTION ON: ONE SIDE	BOTH SIDES
4	20,000	—
6	30,000	57,000
8	40,000	76,000
10	50,000	95,000

Where traffic signals interrupt the traffic flow, the previous analysis does not adequately describe the potential for lane changing for an equivalent volume level. The red phase of the signal concentrates the average stream density into a stopped queue. When the green phase is displayed, the vehicles move out in a platoon at a very high equivalent density. Vehicles retain the platooned effect as they travel down the roadway for a considerable distance. It is proposed that potential lane changing may exist if the adjacent lane was occupied at the stopline during the previous red phase.

When vehicles stop at a signalized intersection, they tend to fill all remaining unfilled spaces in a manner that tends to minimize their delay. Consider a three-lane approach to an intersection on a divided arterial. If three vehicles arrived during the red phase, all three first-position spaces at the head of the queue could be filled. Thus, the driver in the middle position would have internal traffic friction on both sides. If only two vehicles arrived, each driver would have only one-side internal traffic friction.

Drew (*8*) has shown that light traffic volumes, such as at night, tend to be Poisson in character. Drew also shows that, 25 percent of the time, three vehicles would arrive when the average is 1.8 and two vehicles would arrive when the average is 1.0. The following minimum volume warrants use these results to analyze an intersection operation that is assumed to have a cycle length of 50 sec and a red phase of C/2 (a 50/50 split). The minimum hourly approach volumes to warrant internal traffic friction on a divided facility would be

$$q = \frac{3{,}600 \times 1.0}{25 \text{ sec}} = 144 \text{ vph} \qquad \text{(one side)}$$

$$q = \frac{3{,}600 \times 1.8}{25 \text{ sec}} = 259 \text{ vph} \qquad \text{(both sides)}$$

Assuming a directional distribution factor, *D*, of 60/40 and a night hourly volume to average daily traffic ratio, *K*, of 0.05, the minimum average daily traffic volumes which warrant consideration of internal traffic friction are approximately 5,000 vpd (one side), and 9,000 vpd (both sides). It should be apparent that at least three lanes in one direction are required to generate this type of internal friction on both sides of a driver. In general, a six-lane arterial would be the minimum facility to experience this level of friction. It follows that a four-lane facility is the required minimum to generate internal friction on one side.

Medial Friction

Medial friction arises due to the interaction between opposing traffic streams and the interface between them. Any median that is curbed, discontinuous, or less than 30 ft in width with an average daily traffic volume of 10,000 vpd or more should be considered to present one marginal friction scan area.

On undivided streets and highways, the effects of the headlights of approaching vehicles are pronounced on unlighted facilities and the possibilities of head-on collisions exist. Although only one oncoming vehicle is required to have a head-on collision or to produce glare, one approaching vehicle would not realistically describe the information work load brought about by drivers being required to scan oncoming traffic for improper lane positioning.

It is assumed that when an oncoming vehicle is within 500 ft the driver will experience medial traffic friction. As before, an exposure rate of 25 percent of the time for average conditions is used. For continuous flow, the minimum average density to meet the criterion would be $k = \frac{25\% \times 5{,}280}{500 \text{ ft}} = 2.64$ vpm (left side). Again, by use of Greenshield's model to convert this density into equivalent volumes with $k_j = 130$ vplm, $u_f = 60$ mph, and by use of a directional distribution factor of 60 percent and a night hourly volume ratio of the average daily traffic of 0.05, the minimum total average daily traffic warranting volume for medial traffic friction for undivided highways, regardless of the number of lanes, would be about $Q = \frac{60(2.4) - (60/130)(2.4)^2}{0.6 \times 0.05} = 4{,}750$ vpd. A working value of 5,000 vpd is recommended. On undivided facilities having interrupted or signalized traffic flow, a minimum left-side internal traffic volume warrant of 4,000 vpd is recommended. This accounts for the additional exposure oncoming vehicles exhibit for a given traffic volume due to the delay time at signals.

Marginal Friction

Marginal friction may arise due to curb parking and unloading, driveway use, and pedestrian traffic. Examples of land-use activities that create high night marginal friction are shopping centers, convenience stores, restaurants, clubs, motels, and service stations. Because these types of establishments tend to cluster on both sides of the roadway, they may produce marginal-friction hazard areas on both sides of the driver unless a barrier median or other protective separation is provided.

To determine if a section of roadway is subjected to marginal friction, an approach similar to that previously presented is used. To be classified as marginal friction from the driver's viewpoint, the activity area should be restricted to a distance of 500 ft ahead. If it were not, the driver would obtain the information as he scans ahead, if visible, and would not require a scan into the marginal area. If it is assumed that vehicle movements in the marginal area (entering, parking, and unloading and vice-versa) would be noticeable for 30 sec, the minimum average night driveway volume per hour per 500 ft would be $q = \frac{3{,}600 \times 25\%}{30} = 30$ vph per 500 ft, using a 25 percent exposure rate as before. A vehicle entering and leaving a business would be considered two counts. Sixty vehicles per hour would warrant both sides, where possible. No equivalent average daily traffic should be assigned, because the night activity is highly dependent on the related commercial business class.

Intersection approach volumes that were not used to successfully warrant an intersection within a section should be considered in the analysis of marginal friction. However, to qualify as marginal friction a much lower effective volume must be used due to the differences in marginal exposure times. Minor intersection marginal exposure times are probably no more than 10 sec. Thus, intersection approach volumes should be divided by three before being added to the driveway volumes.

It is recommended that two 500-ft sections per mile must warrant marginal friction before the roadway can be considered to have a sufficient marginal friction situational information work task. Curbside parking and bus stop operations occurring at night within a 500-ft section would automatically warrant the section as having marginal friction on the side presented on undivided facilities.

A summary of the situational task scan areas, the warranting conditions, and recommended guidelines is presented in Table D-1. Six types of situational information sources are considered. Intersectional, internal, medial, and marginal friction have been previously described. The fifth, the roadway ahead, is always a situational scan area.

Traffic signals, stop signs, and yield control devices create an additional situational scan area. At least two per mile are required on a roadway for continuous warranting of this situation. Thus, almost all streets in an urban area have at least two situational scan areas—the road ahead and traffic control devices that allocate the right-of-way.

Due to the increased complexity of the object and scene being viewed, the mean fixation durations of situational information tasks are slightly longer than for positional tasks. Mourant et al. (*4*) found that the mean fixation durations of vehicles, signs, and other objects were about 0.31 sec. Because several scan areas are considered, each somewhat close to the next, the visual angle required to shift from one to another is relatively small. As a consequence, the visual eye movement time is assumed to be 0.04 sec. Thus, the total time required to satisfy the situational level information tasks is obtained by multiplying the total number of warranting situational information scan areas from Table D-1 by 0.35 sec.

Navigational Information Tasks

In following the concept of the primacy of information, only after the positional and situational information needs of the driving tasks have been serviced and found satisfactory can the driver proceed to search for navigational information that he may need. The type of information sought would consist of the directional finding information that the driver requires to reach his selected destination. The amount of directional finding information required depends on the driver's previous driving experience in reaching his destination, his *a priori* information with respect to the route selected, and the complexity of the required navigational decisions.

Mourant et al. (*4*) found that the average fixation time of drivers on roadside signs was about 0.31 sec. Mitchell and Forbes (*9*) derived an expression for the time to read three familiar words on a sign to be $N/3$, or 0.33 sec per word. A value of 0.32 sec per word is used here. This value does not include an eye movement time, which is assumed to be 0.03 sec. Thus, each word requires an average of 0.35 sec to find and read.

It would seem reasonable to assume that an "informed" driver, most likely a local driver who is informed due to his previous driving experience on a particular facility, needs only one visual cue or one word to satisfy his navigational needs. That is, once he is aware of his location along the facility, he knows how and when to make any necessary traffic maneuvers to continue along his desired route. The informed driver would then require only about 0.35 sec to satisfy his navigational needs. The geometric complexity of the intersection or interchange would have little effect on the navigational information needs of the informed motorists. All junctions should provide for at least this navigational task capability.

The "uninformed" or nonlocal motorist requires more time and information or navigational "words" to make an efficient navigational decision than does an informed motorist. In searching for the desired information, the uninformed motorist may read at least one uninformative word for each lane except one. This is because most multilane facilities, especially freeways, have one overhead guide sign per lane approaching an interchange. After locating the correct overhead guide sign, the motorist would need to read at least two informative navigational words describing the appropriate route number or control city and the direction or lane assignment. Thus, the time, T_N, required by an uninformed motorist to satisfy his navigational information needs at an interchange or intersection would be

$$T_N = 0.35\left(\frac{l}{2} + 1\right) \tag{D-6}$$

in which l is the total number of through lanes of the roadway.

For an interchange or intersection to warrant "uninformed motorists" conditions, it is recommended that at least one uninformed motorist would have to arrive at the interchange for each direction of flow on the roadway at least once per minute 75 percent of the time during the night design hour. If Poisson arrivals are assumed, this criterion requires a minimum of 230 uninformed motorists per hour for both directions. It is assumed that uninformed traffic on freeways is 25 percent in rural areas, 20 percent in suburban areas, and 15 percent in urban areas. The ratio of the night design hourly volume to average daily traffic for all cases is assumed to be 0.05 sec as before.

It is recognized that the geometric complexity of the interchange and the expectance of the driver should also be considered in evaluating the navigational information task difficulties and needs. Diamond interchanges are perhaps the most expected and the easiest to evaluate and navigate. Cloverleafs are assumed to be approximately one-third more demanding. Partial cloverleafs, wyes, trumpets, and directional interchanges are not expected by the uninformed driver and frequently are more difficult to negotiate. These types of interchanges are assumed to be 50 percent more demanding than the simple diamond interchange. In essence, what is being implied is that only one-half the traffic volume would be required to warrant a partial cloverleaf interchange than would be required to warrant a diamond.

Table D-2 gives the minimum average daily traffic volume required to warrant an uninformed motorist navigational task time. This volume includes the sum of the roadway's through, exiting, and entering volume for each direction at the interchange.

As before, at least two warranting intersections per mile are required to achieve consideration for a continuous warranting of lighting conditions. Consideration of warranting continuous lighting on freeways requires at least one warranting interchange every 1½ miles.

COMPUTATION OF THE POSITIONAL INFORMATION SUPPLY WITHOUT FIXED ROADWAY LIGHTING

The supply of positional information in the form of lane lines, edgelines, and curb delineation was considered by the participants in the diagnostic study phase of this research to be the most critical and most needed information. All other tasks at the situational and navigational levels depended on the sufficiency of these visual inputs. The subjects insisted that more orderly consideration and accomplishment of the situational and navigational task was possible when positional information was readily available.

Model of Positional Information Supply

The supply in time of positional information is computed from

$$C = \frac{\bar{L}}{1.47\, V_r} \tag{D-7}$$

in which C is the positional information supply, in seconds; V_r is the running speed of the traffic, in miles per hour; and $\bar{L}$ is the average visibility distance of the critical source of positional information ahead of the driver without fixed roadway lighting. It is apparent that the supply of positional information increases with increasing visibility distances and decreases as the speed of the driver increases. The critical source of positional information in this model is assumed to be the lane lines.

The visibility distance of a lane line is known to depend on its contrast, its brightness as determined by the vehicles headlights on dim, its width, and the amount of disability glare in the driver's field of view. This model is developed from visibility research findings and theory of others and then calibrated with data obtained in a controlled field study to ensure that satisfactory visibility distances would be obtained.

The basic visibility equation was developed from research presented by Adrian (*10*). The relationships between brightness differences, between the target and its background, and the minimum size of the target that would have a 100 percent probability of detection were presented. In this model, the target is the lane lines and the background is the pavement surface. The following equation was developed from Adrian's research, which relates the visual angle to the brightness and brightness differences:

$$\alpha = \frac{1.66 B_p^{0.327}}{(B_l - B_p)^{0.654}} \qquad \text{(D-8)}$$

in which

α = The minimum visual angle, in minutes of arc;
B_p = The brightness of the background pavement, in foot-lamberts; and
B_l = The brightness of the lane lines, in foot-lamberts.

The visual angle of the target is assumed to be determined by the width of the lane line, R, in inches, and the resulting visibility distance of the lane line, L. Substituting for α a value of 287 R/L results in the following equation for the visibility distance, L:

$$L = 173 \frac{R(B_l - B_p)^{0.654}}{B_p^{0.327}} \qquad \text{(D-9)}$$

The effects of glare can be included in the visibility distance equation by adding the disability veiling brightness, G, to the initial brightness of the object and background. The glare, G, is the sum of all the glare effects from glare sources in the driver's field of view. The visibility equation thus becomes

$$L = 173 \frac{R[B_l + G - (B_p + G)]^{0.654}}{(B_p + G)^{0.327}} = 173 \frac{R[B_l - B_p]^{0.654}}{[B_p + G]^{0.327}} \qquad \text{(D-10)}$$

The intensity of the low-beam headlight illumination on the lane lines and pavement surface near the anticipated visibility distance was estimated from photometric headlight data provided by a national manufacturer of highway signing materials. These data suggested that the illumination in foot-candles could be estimated by

$$E = \frac{5{,}000}{d^2} \qquad \text{(D-11)}$$

in which d is the distance from the vehicle to the location on the lane line where the intensity of illumination is desired. Here, this desired distance is the visibility distance, L.

With E, the intensity of illumination (in foot-candles) known, the brightness of the lane line was computed from

$$B_l = \rho_l E \qquad \text{(D-12)}$$

in which ρ_l is the reflectance factor of the lane lines, and the brightness of the pavement surface was computed from

$$B_p = \rho_p E \qquad \text{(D-13)}$$

TABLE D-2

MINIMUM AVERAGE DAILY TRAFFIC [a] TO WARRANT UNINFORMED MOTORISTS' NAVIGATIONAL INFORMATION TASK [b, c, d, e]

	MINIMUM ADT REQUIRED		
TYPE	RURAL LOCATION	SUBURBAN LOCATION	URBAN LOCATION
Interchanges:			
Diamond	18,000	23,000	30,000
Cloverleaf	13,000	17,000	22,000
Directionals	9,000	11,000	15,000
Parclos	9,000	11,000	15,000
Wyes	9,000	11,000	15,000
Trumpets	9,000	11,000	15,000
Intersections	5,000	10,000	15,000

[a] Sum of roadway's six volumes: two through, two off, and two on.
[b] All intersections and interchanges warrant at least 0.4-sec navigational information task time.
[c] A minimum of two warranting intersections every mile and one warranting interchange every 1½ miles is required for consideration of continuous lighting warranting.
[d] The crossing roadway must have an ADT at least 20 percent of the value shown.
[e] When warranted, $N_i = T_N = 0.35 \left(\frac{l}{2} + 1\right)$, in which l is the number of lanes on the facility.

in which ρ_p is the reflectance of the pavement surface. Thus, the visibility equation becomes

$$L = \frac{173R\left[\dfrac{5{,}000\rho_l}{L^2} - \dfrac{5{,}000\rho_p}{L^2}\right]^{0.654}}{\left[\dfrac{5{,}000\rho_p}{L^2} + G\right]^{0.327}} \qquad \text{(D-14)}$$

The disability veiling brightness or glare was computed from the generalized Holladay-Stiles formula:

$$G = \frac{10\pi E_V}{\theta^n} \qquad \text{(D-15)}$$

in which

G = Disability veiling brightness, in foot-lamberts;
E_V = The illumination striking the plane of the driver's eyes;
θ = Incident angle of the glare source, in degrees; and
n = Generalized exponent.

The amount of oncoming vehicle headlight glare is dependent on the lateral separation, s, between an oncoming vehicle and the vehicle affected, and the longitudinal separation, X, between the two vehicles. The distance between the two vehicles would then be

$$h = \sqrt{X^2 + s^2} \qquad \text{(D-16)}$$

The average effective left-side candlepower for dim lights was assumed to be 2,000 at the driver's eye height based on the headlight data available. It is recognized that vehicle headlights form a directionally oriented beam of light and do not act exactly as a point source of light. However, to simplify the calculations, the point source was assumed and the effective candlepower was determined by calibration to the photometric data at approximately 200-ft longitudinal separation and 9-ft lateral separation.

Substituting $E \cos \theta$ for $E_{l'}$ in the Holladay-Stiles glare equation (Eq. D-15) where $\cos \theta = X/(X^2 + s^2)^{1/2}$, and letting $E = 2{,}000/h^2$, results in

$$G = \frac{10\pi}{\theta^n} \frac{X\ 2{,}000}{(X^2 + s^2)^{1/2}(X^2 + s^2)} \quad \text{(D-17)}$$

Assuming that $\sin \theta = \theta$ in radians and converting θ in radians to degrees yields

$$G = \frac{10\pi\ X\ 2{,}000}{(57.3)^n \dfrac{s^n}{(X^2 + s^2)^{n/2}} (X^2 + s^2)^{1/2}(X^2 + s^2)} \quad \text{(D-18)}$$

Several values for the exponent n were tested in the range from 1.0 to 2.0. A value of $n = 1.0$ was found to correlate best with the field data recorded in this research and a value of 1.0 also simplifies the glare equation. Thus, using $n = 1.0$ results in

$$G = \frac{10\pi\ X\ 2{,}000}{57.3\ (X^2 + s^2)s} \quad \text{(D-19)}$$

Hence, the visibility distance equation (Eq. D-14) becomes

$$L = 173R \frac{\left[\dfrac{5{,}000\rho_l}{L^2} + \dfrac{5{,}000\rho_p}{L^2}\right]^{0.654}}{\left[\dfrac{5{,}000\rho_p}{L^2} + \sum \dfrac{10\pi\ X\ 2{,}000}{57.3(X^2 + s^2)s}\right]^{0.327}} \quad \text{(D-20)}$$

or

$$L = \frac{2{,}800\ R\ [\rho_l - \rho_p]^{0.654}}{L^{1.346}\left[\dfrac{\rho_p}{L^2} + 0.022 \sum \dfrac{X}{(X^2 + s^2)s}\right]^{0.327}} \quad \text{(D-21)}$$

In the field test, a white beaded paint was used to construct 4-in. dashed lane lines on a concrete pavement. The reflectance factor was assumed to be 0.3 for the pavement and 0.7 for the reflective paint. Use of these assumptions and $R = 4.0$ yields

$$L = \frac{5{,}100}{L^{1.346}\left[\dfrac{0.3}{L^2} + 0.022 \sum \dfrac{X}{(X^2 + s^2)s}\right]^{0.327}} \quad \text{(D-22)}$$

The model was then calibrated with field data to ensure acceptable legibility results. The calibration analysis revealed that the coefficient should be about 4,000 instead of 5,100. This small percentage calibration indicates the reasonableness of the model. Figure D-1 shows the final calibrated results as compared to the field data.

The difficulty in computing the visibility distance is that the solution is by trial and error; that is, the visibility distance must be assumed to compute the brightness, which in turn affects the visibility distance.

It is well known that the visibility of the roadway ahead of the driver is reduced due to oncoming vehicle headlight glare. As the volume and density of oncoming vehicles increases, the visibility is reduced. However, the visibility increases as the lateral separation between opposing traffic flows is increased.

These facts are reflected in the results of the application of the visibility model to various traffic operational conditions (Fig. D-2). These results were obtained by summing up the glare contribution to a driver caused by every vehicle in the opposing traffic stream that would be present within 1,000 ft of the driver. The effects of up to 500 vehicles were computed. A uniform spacing was assumed in the opposing traffic flow, with the first vehicle in the opposing

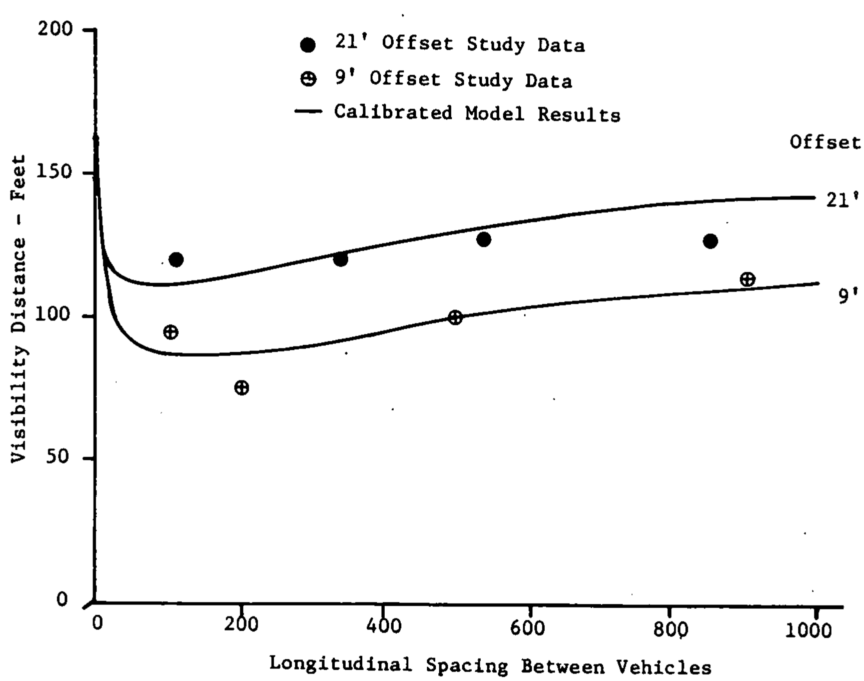


Figure D-1. Visibility distance of 4-in. lane line as a function of lateral offset and distance of oncoming vehicle's lights.

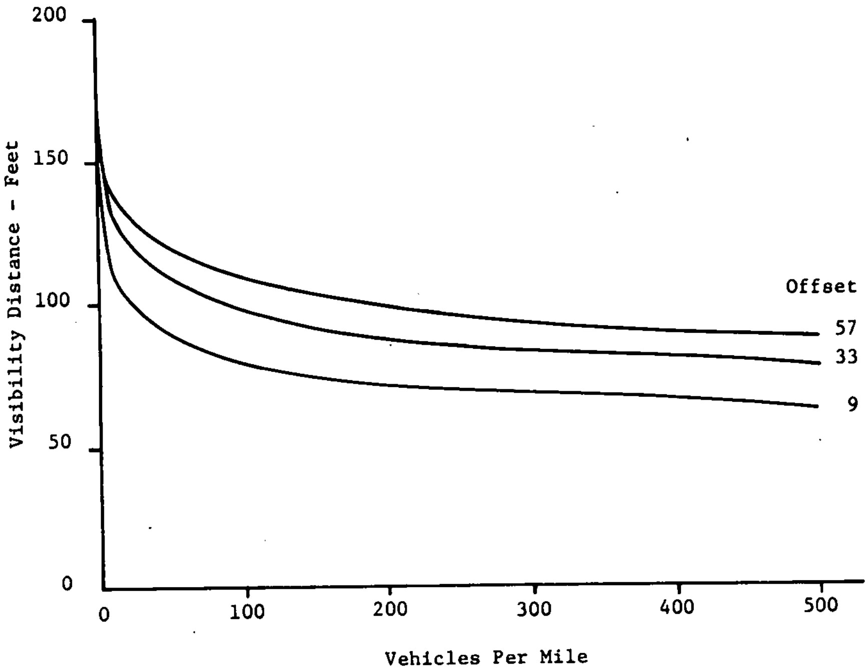


Figure D-2. Low-beam positional visibility distance as a function of oncoming vehicle density and lateral separation.

traffic flow positioned one-half of the average spacing in front of the affected motorist.

Discussion

In essence, the oncoming vehicle headlights are sources of light that produce glare in the driver's eyes. Environmental lighting could also be considered similarly. Certainly, the glare caused by different roadside establishments varies widely. On the other hand, it seems impractical to require that they be counted or that their effects be measured directly. The objective, then, is to develop a practical method of incorporating roadside lighting into the approach being developed.

If it is assumed that 52.8 ft of frontage of an establishment that is lighted at night has a glare equivalent of 1 oncoming vehicle, a traffic facility that has 100 percent roadside lighted development on one side would be equivalent to a vehicle light source density (as in Fig. D-2) of 100 vehicles per mile, or a 100 percent lighted development on both sides of 200 vehicles per mile. A 50 percent development on both sides would be equivalent to 100 vehicles per mile, etc.

To simplify the computation, the roadside lighting is assumed to be located at the same offset as the oncoming vehicle headlights. Although this assumption may seem to be unjustified, the principal objective is to include the roadside environmental effects in some reasonable way rather than to neglect them entirely.

Procedure for Computing Positional Information Supply

The procedure for computing the positional information supply, in seconds, is presented in the following and summarized in Figure D-3. The procedure considers general visibility, as previously discussed, including oncoming vehicle glare and roadside development. Also considered are the percentage of time the driver will be using high and low beams as related to traffic flow conditions, the average horizontal alignment, and the average running speed of the driver.

Step A. The first step in the procedure is to compute the visibility distance of the lane lines, as shown in Figure D-3a. Four items of data are required: (1) Q, the opposing traffic stream volume during the night design hour; (2) V_0, the operating speed of the opposing flow for the previous volume; (3) the average lateral offset of the opposing stream flow with respect to the inside lane in the driver's flow; and (4) the average percentage development along the facility.

To illustrate, assume that the facility being analyzed is a 4-lane divided arterial having 12-ft lanes and a median width of 18 ft. The lateral offset is $3 + 18 + (24/2) = 33$ ft. The directional volume, Q, is assumed to be 300 vehicles per hour during the night design hour. Due to signalization, the operating speed in the opposing flow, V_0, which includes delay time, is 30 mph. To simplify computation, the flow or speed is assumed to be the same in each direction of flow. The average roadside development that has exterior lighting is 45 percent for both sides.

Referring again to Figure D-3a, the number of glare sources per mile is $(Q/V_0) + 200 \times \%$ development, or $(300/30) + 200 \times 45\% = 100$.
Use of this result and the 33-ft lateral offset in Figure D-3a gives low-beam visibility distance of 100 ft. This answer is used later in the procedure in Figure D-3d.

Step B. A driver traveling along a roadway at night gen-

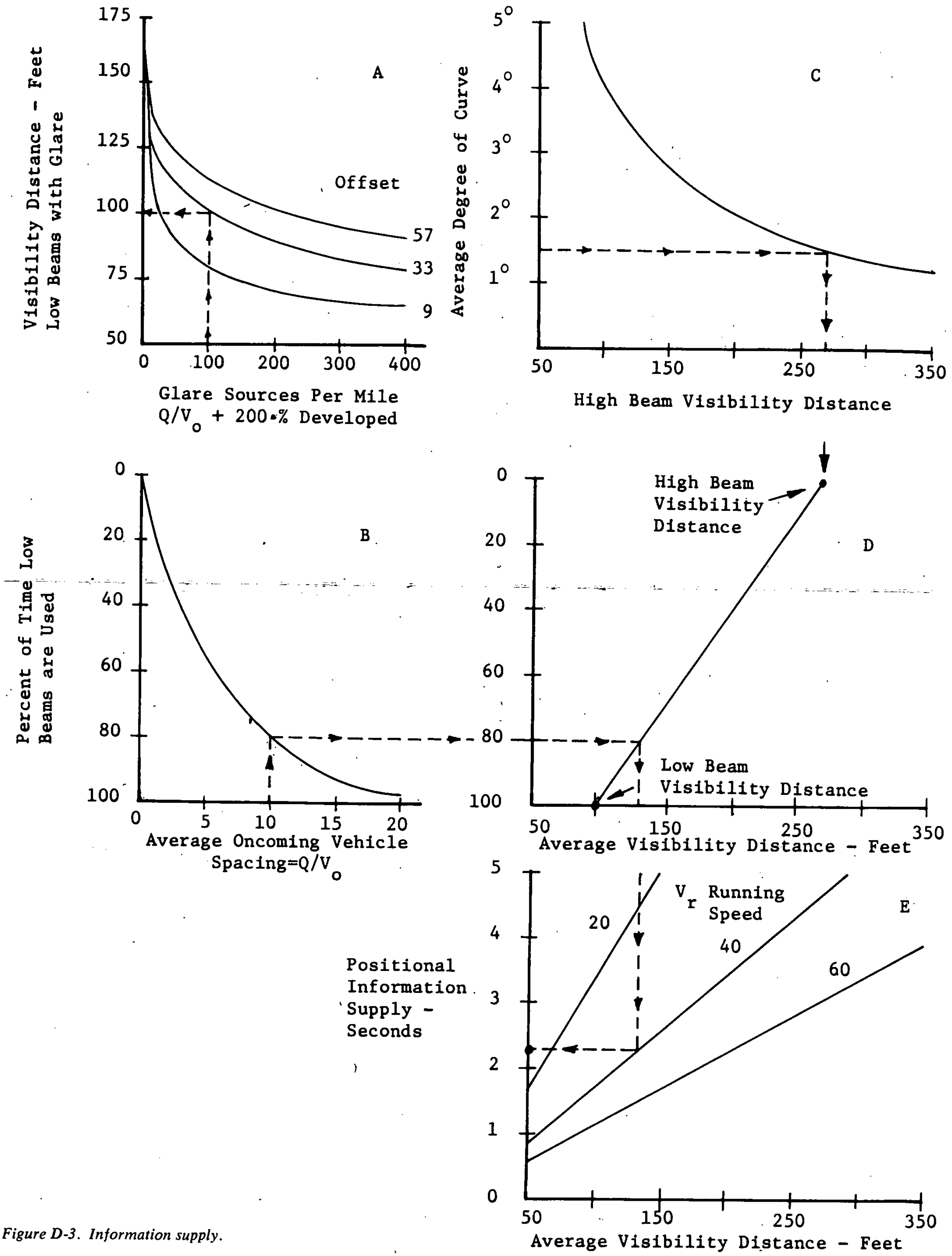


Figure D-3. Information supply.

erally uses both his high- and low-beam headlights. On low-volume rural highways, the driver would use his high beams a large percentage of the time, whereas in urban areas low-beam use would predominate. This must be taken into account in estimating the average positional information supply. Figures D-3b and D-3d were developed to satisfy this requirement.

Figure D-3b shows the average percentage of time a driver would be using his low-beam headlights as a function of the traffic volume in the opposing direction of flow, Q, and its average operating speed, V_o. This figure is based on the assumption of Poisson flow and on the assumption that opposing drivers dim their lights at a 1,000-ft longitudinal separation distance. Again, using the data given ($Q = 300$, $V_o = 30$) Figure D-3b indicates that 80 percent of the time the affected driver would be using his low-beam headlights. This answer is transferred across to Figure D-3d.

Step C. The next step is to compute the average high-beam positional visibility distance. The maximum high-beam visibility distance of positional information on a straight roadway is assumed to be 400 ft without fixed-source roadway lighting. However, as the average degree of curvature of the roadway increases, the visibility of the pavement surface and lane lines is reduced, because the roadway is curving away from the headlights. Figure D-3c is based on the assumption that a vehicle's high-beam headlight pattern will permit lane lines to be visible up to a 2° angle of divergence with the longitudinal axis of the vehicle.

The average degree of curvature of a roadway is computed by summing the degree of curvature at each 100-ft station and dividing the sum by the number of stations considered. In this example, it is assumed that the average curvature was found to be 1.5°. From Figure D-3c, a 1.5° curvature results in an average high-beam visibility distance of 270 ft.

Step D. As shown in Figure D-3d, after the visibility distances for high beams (270 ft) and low beams (100 ft) are plotted at 0 percent and 100 percent low beam used, an average positional visibility distance, $\bar{L}$, of 134 ft is computed for the 80 percent low-beam operation existing in the example. This figure solves the equation

$$\bar{L} = \%\text{ low beam } (L) + (100\% - \%\text{ low beam})(L_{\text{high beam}}) \qquad \text{(D-23)}$$

Step E. The final step is to compute the positional information supply, in seconds, knowing the average visibility distance in feet, $\bar{L}$ (here 134 ft) and the average running speed, V_r, which for the example is assumed to be 40 mph. Figure D-3e shows that the positional information supply, C, is 2.3 sec. Figure E-3e solves the equation

$$C = \frac{\bar{L}}{1.47V_r} \qquad \text{(D-24)}$$

APPLICATION OF DRIVER INFORMATION MODEL IN WARRANTING FIXED ROADWAY LIGHTING

Fixed roadway lighting has many beneficial aspects. It improves roadway visibility and traffic operations, improves the criminal surveillance capabilities of the police, and may express the objectives and attitudes of the community. The value of fixed roadway lighting, then, depends on the values of the group in question.

Warranting Fixed Roadway Lighting

The approach used here to warrant fixed roadway lighting is based on the driver's information needs to perform his driving task on the facility in question within the driving environment present. From this viewpoint, fixed roadway lighting is warranted along a section of roadway or at interchanges or intersections when the information demand exceeds the information supply without fixed roadway lighting.

The information demand is the time required to fulfill the sequence of positional, situational, navigational, and redundant positional information searches. That is, the demand is

$$D = \Sigma(P_i + S_i + N_i + P_{i+1}) \qquad \text{(D-25)}$$

in which

D = Information demand, in seconds, on a section of roadway;
P_i = Time required to obtain positional information on cycle i;
S_i = Time required to obtain situational information on cycle i;
N_i = Time required to obtain navigational information on cycle i; and
P_{i+1} = The next required positional information search update on cycle $i = 1$, which must be achieved within the section of roadway visible during P_i. ($P_{i+1} = P_i$ in time.)

The time required by the driver to make a positional update, P_i, is computed from Eq. D-4. However, two positional updates are required, each of the same duration, within a given supply time. The time required to satisfy the situational information needs, S_i, for a facility is computed by use of Table D-1. The time required to make a navigational update is 0.0 between junctions, 0.4 sec where intersections and interchanges do not warrant a higher level, and $0.35\left(\frac{l}{2}+1\right)$ seconds where this higher level is warranted, as given in Table D-2.

Substitution of the results from Eq. D-4 for both P_i and $P_{i=1}$, determination of S_i from Table D-1, and evaluation of N_i from Table D-2, gives the information demand, D, as

$$D = 1.5\,\frac{[D^\circ + 2]}{W - 7} + S_i + \left[0.0, 0.4, 0.35\left(\frac{l}{2} + 1\right)\right] \qquad \text{(D-26)}$$

in which

D = Information demand, in seconds;
D° = Average degree of horizontal curvature, in degrees;
W = Average lane width (for a one-lane turning roadway use pavement width — 5 ft);
S_i = Situational information time demand (Table D-2); and
l = Number of facility lanes.

The positional information supply depends on the suitability of the night driving environment without fixed roadway lighting. The positional information supply in seconds, C, is computed from Figure D-3.

To check a section of roadway to determine if fixed roadway lighting is warranted, the information index, I, is computed as

$$I = \frac{D \text{ (information demand)}}{C \text{ (information supply)}} \qquad \text{(D-27)}$$

and fixed roadway lighting is warranted if $I > 1$. It is recommended that 500-ft sections of roadway be analyzed.

Noncontinuous Warranting

On roadways that will not warrant continuous lighting, the interchanges or intersections should be evaluated without the continuous warranting requirements. The interchanges and intersections that will warrant lighting (where the roadway itself does not warrant continuous lighting) should be considered to warrant complete area lighting. Partial interchange lighting might be based on an individual movement analysis.

Establishing Priorities

The decision-maker, who allocates funds to various competing warranting lighting projects, needs a rational approach to use in allocating funds so as to maximize the benefits to the motoring public. One such approach is to compute an equivalent priority index, P_X, for any warranting lighting project, X, and to compare it to all other competing projects. With all competing priority indices ranked in order from highest to lowest, selections would be made from the top until either all the available funds were expended or until some minimum acceptable spending level of priority was reached based on historical needs.

The recommended procedure for computing the priority index for a warranting lighting project is

$$P_X = \frac{\sum_{i=1}^{D} I_i Q_i d_i}{C_i} \qquad \text{(D-28)}$$

in which

P_X = Priority index of warranted lighting, project X;
I_i = Information index of warranted roadway, section i;
Q_i = Average daily traffic on roadway, section i;
d_i = Length of warranted roadway, section i;
D = Number of sections warranted on roadway; and
C = Present-worth cost of lighting, operating, and maintaining the complete project.

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APPENDIX E

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