

STATE OF THE ART IN WARRANTS FOR FIXED ROADWAY LIGHTING

Neilon J. Rowan

The basic motivation for using 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: crime reduction, civic improvement, and traffic safety.

The history of street lighting dates back to the fifteenth century, when citizens of London and Paris began to carry 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 Europe. Changes in lamp innovations for street and roadway lighting took place over the years. Today, a number of light sources with efficiencies of 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 installed 4 steel masts, 250 ft in height. Because it had been decided by 1883 that higher mounting heights produced inefficient light, 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, Texas.

Modern practice has seen mounting heights increase from 20 to 60 ft. Many states are now employing high-intensity lighting sources and, consequently, are returning to mounting heights of 60 to 200 ft for special lighting situations, such as complex interchanges.

WARRANTS FOR FIXED LIGHTING

The literature is abundant with information on the 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 warrants. These warrants are based primarily on engineering experience and judgment and have little, if any, factual basis.

Existing warrants for the installation of fixed lighting do not reflect adequate consideration of the many factors that affect the driving task. The principal requirement of the driving task is an informational requirement: The driver must be able to see the roadway, environmental, and traffic elements that affect the driving task in sufficient time to respond safely and efficiently.

This paper will deal with a detailed evaluation of the currently available published information (1, 2, 3) on guidelines and warrants for fixed lighting.

AASHO WARRANTS

The most widely accepted set of warrants for roadway lighting is that published by the American Association of State Highway Officials (AASHO). The purpose of this review is to critically examine the following warrants suggested by AASHO (1) from the point of view of reasonably fulfilling the driver's needs.

Warrants for Continuous Freeway Lighting

Case A-1: Continuous freeway lighting is considered to be warranted where for a length of 2 or more miles it passes through a substantially developed suburban or urban area in which one or more of the following conditions exist: (a) local traffic operated on a complete street grid having some form of street lighting, parts of which are visible from the freeway; (b) the freeway passes through a series of developments such as residential, commercial, industrial and civic areas, colleges, parks, terminals, etc., which include roads, streets, and parking areas, yards, etc., that are lighted; (c) separate cross streets, both with and without connecting ramps, occur with an average spacing of ½ mile or less, some of which are lighted as part of the local street system; and (d) the freeway cross section elements such as median and borders are substantially reduced below desirable sections used in relatively open country because of the high costs of right-of-way due to proximity of existing land developments.

The 4 conditions defined in Case A-1 are all situations that could justify the installation of fixed illumination. In condition a, the reasons for excluding street systems that are other than a complete grid system are not apparent; however, the other warranting conditions would include any design configuration. In condition b, reference is made to a series of developments that are lighted along the facility. This situation could occur along virtually any section of an urban freeway. The question is, rather, to what degree the roadside development contributes to the need for fixed external illumination. Three situations could exist in this regard, 2 of which would not justify the provision of external illumination:

1. The level of illumination, in combination with the geometric and terrain conditions, does not result in a situation in which the roadway appears darker than the general environment. Fixed illumination, therefore, would not be required as a result of the environmental lighting circumstances.
2. The level of illumination associated with the roadside development is sufficient to produce a situation in which the roadway appears much darker than the surrounding area. Under these conditions, lighting of the facility would most certainly result in greater confidence on the part of the driver while on the facility.
3. The spillover from the lighting associated with the roadside development is sufficient to outline the geometric features of the roadway for most of the roadway length; thus, the need for continuous lighting would not exist.

Condition c states that continuous lighting is warranted when spacing between interchanges or grade-separated roadways or both averages ½ mile or less, some of which are lighted as a part of the local street system. The number of interchanges lighted and/or the degree to which they are lighted have not been specified. It appears that an assumption has been made that interchanges and/or grade separations so closely spaced would result in a rather complex geometric design that, in turn, would warrant continuous illumination. The fact that some of the separation structures are lighted (including degree of luminosity) seems incidental to the warranting condition.

In the design of freeways in urban and suburban areas, it is generally accepted that openings at approximately ½-mile intervals are desirable when it is practical to provide such openings. Therefore, most sections of urban freeways could warrant installation of fixed lighting by virtue of the basic design alone, if one or more of the crossing roadways is lighted. Condition c is, therefore, not a warrant per se; rather, it permits the installation of continuous lighting on urban freeways when the decision-maker is of the opinion that it is justified and also as funds for installation become available.

Condition d alludes to a warrant based on a reduction in desirable design features due to the high cost of right-of-way in urban areas. The phrase "substantially reduced

below desirable sections" is used in the definition statement. Without some additional qualifying statements, this condition is too vague to provide the decision-maker with a tool for including or excluding as he sees fit almost any section of urban freeway in the warranted sections of roadway. There is little doubt that virtually every mile of urban freeway is built to a lower standard than would be used in open country. The key word is "substantially," and, because each individual has a different connotation as to that which constitutes a substantial reduction regarding design standards, the decision to warrant fixed illumination under Case A-1, condition d, is based on personalities rather than on objective decision-making.

Case A-2: Continuous freeway lighting is considered to be warranted on those sections wherein three or more successive interchanges are located with an average spacing of $1\frac{1}{2}$ miles or less, and adjacent areas outside the right-of-way are substantially urban in character.

Case A-2 is a repeat of Case A-1, condition c, without the requirement that one or more of the interchanges be lighted as a part of the local street system. This appears to be a recognition of the fact that closely spaced interchanges create a difficult and complex driving environment in which the driver should be kept informed of geometric conditions ahead. It is again worthwhile to note that current practice calls for openings at approximately $\frac{1}{2}$ -mile intervals; thus, many miles of urban freeway could warrant fixed illumination on the basis of the basic design criteria.

Case A-3: Continuous freeway lighting is considered to be warranted on those sections in and near cities where the current ADT is 30,000 or more.

The concept that the benefits derived from lighting a freeway are directly related to the volume of traffic using that facility has resulted in attempts to justify, on the basis of traffic volume alone, the installation of fixed illumination. It is apparent, however, that traffic volume alone cannot justify lighting. A section of freeway that has no merging or diverging areas, is essentially straight, and has well-defined lanes of adequate width would probably not need external illumination, whereas a complex series of interchanges could require external illumination for traffic volumes well below the cited value.

Other difficult situations for the driver can be alleviated by the use of external illumination. For example, on a multilane freeway section during wet conditions, the painted lane lines are lost, and the headlights do not illuminate the extremities of the roadway sufficiently to permit the driver to discern the lane lines. The driver is essentially lost in a mass of pavement with few, if any, clues to guide him. Although other treatments may be more effective in increasing the lane line visibility, the definition of the extremities of the roadway can be effectively accomplished using external illumination.

The use of a definite traffic volume as a warrant for fixed illumination must be considered questionable. The value of 30,000 ADT was reported to have been selected so that only a few sites would warrant fixed illumination. This was done because many highway administrators feared that public pressure would result in freeways being lighted on the basis of traffic volume alone. The philosophy is undoubtedly valid, and the other warranting conditions would cover the other cases. The difficulty in using a specific traffic volume as a warrant occurs when an individual responsible for review of roadway lighting simplifies the decision-making process by using the volume warrant as an absolute measure rather than as a guide. All other warranting conditions, therefore, become secondary to traffic volume.

Case A-4: Continuous freeway lighting is considered to be warranted on those sections where the ratio of night to day accident experience is high (say, higher than the statewide average for all unlighted similar sections) and a study of conditions indicates that lighting may be expected to result in a significant reduction in the night accident rate.

The use of the accident rate as a basic warrant for continuous illumination is, at best, somewhat questionable. The number of accidents associated with the through segments of the roadway (i.e., other than interchange areas) is usually relatively small.

This fact, coupled with the requirement that the lighting should significantly reduce the night accident rate, means that the overall rate would be very low. For example, if the statewide accident rate on unlighted sections of similar character is 3.0 accidents per million vehicle-miles, the rate on any one section could exceed this value by 50 percent and still be within the normal variation about the mean value. Thus, if the average ratio of night to day accidents is 1.5, and a rate that is 50 percent greater than the average is needed in order to be significant, then the actual rate on any given section of roadway could be twice the average rate without being significantly different in a statistical sense.

This discussion points out a rather obvious fact: If the accident rate at night is due to a lack of adequate illumination, which is likely coupled with poor geometric design, the need for external illumination is usually rather apparent. The use of accident rates to establish the need for safety lighting appears justifiable; however, for warranting continuous freeway illumination, a logical question can be raised regarding the validity of this concept.

Case A-5: Continuous freeway lighting is considered to be warranted where the local governmental agency finds sufficient benefit in the forms of convenience, safety, policing, community promotion, public relations, etc., to pay an appreciable percentage of the cost of or wholly finance the installation, maintenance, and operation of the lighting facilities.

This general warrant is designed to accommodate those special local situations that, in the opinion of the local governmental agency, justify roadway lighting on the basis of indirect benefits to the population as a whole.

Interchange Lighting for Unlighted Freeways

Case B-1: Complete interchange lighting on unlighted freeways is considered to be warranted at locations where existing substantial commercial, or industrial development which is lighted during hours of darkness is located in the immediate vicinity of the interchange or where the crossroad approach legs are lighted for ½ mile or more on each side of the interchange.

The warranting of complete interchange lighting by virtue of the commercial lighting on the intersecting facility is certainly justified. Very often this situation will result in the actual freeway interchange being the darkest spot in the area. This results in a great deal more uncertainty on the part of the driver and, conceivably, could increase the accident probability. The most serious objection to this warrant is its failure to specify the level of lighting on the cross facility and the resultant effect on the freeway traffic stream.

Case B-2: Complete interchange lighting is considered to be warranted where the total current ADT ramp traffic entering and leaving the freeway within the interchange area exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

The values specified for interchanging traffic volume, which will warrant complete interchange lighting, are undoubtedly the result of a group judgment by those individuals responsible for establishing the basic warrants. Professional judgment and experience are apparently the basis for selecting the values, and these values probably represent a fair evaluation of the least amount of ramp traffic that alone could justify complete lighting. It would be desirable, however, to have a more objective basis for selecting these constraints, especially when the decision regarding federal participation is so heavily related to values that were selected in an arbitrary fashion.

Case B-3: Complete interchange lighting is considered to be warranted where the current ADT on the crossroad exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

This warrant seems somewhat inappropriate. The warranting condition is for the crossroad and not the freeway itself. It is difficult to understand how the crossroad

traffic volume, independent of the number of vehicles interchanging between 2 facilities, could justify complete interchange illumination. This is not to say that the need for partial interchange lighting might not be so extensive as to justify the installation of complete interchange illumination.

Case B-4: Partial interchange lighting is considered to be warranted where the total current ADT ramp traffic entering and leaving the freeway within the interchange area exceeds 5,000 for urban conditions, 3,000 for suburban conditions, or 1,000 for rural conditions.

The justification for partial interchange lighting on the basis of interchanging traffic volume seems appropriate. The only question that could be raised involves the values selected. Again, it would appear that geometric conditions, in addition to interchanging volume, should be included in the warrant. This is discussed in the "special considerations" section of the interchange lighting warrant.

Case B-5: Partial interchange lighting is considered to be warranted where the current ADT on the freeway through traffic lanes exceeds 25,000 for urban conditions, 20,000 for suburban conditions, or 10,000 for rural conditions.

The use of through-traffic volume alone as justification for partial interchange lighting is subject to the same criticism as that for continuous illumination (Case A-4). If all the traffic is going through, there is no need for lighting other than that required for the through lanes. Conversely, if the interchange is complex, the need for illumination may be substantial even for relatively low traffic volumes.

Case B-6: Complete or partial interchange lighting is considered to be warranted where the ratio of night to day accident experience is high (say, higher than the statewide average for all unlighted similar interchanges) and a study of conditions indicates that lighting may be expected to result in a significant reduction in the night accident rate.

The problem involved in evaluating the need for fixed illumination on the basis of accident experience has been discussed in some detail previously. A similar discussion of this warrant is of somewhat more limited value here. The only possible difference between the 2 treatments is the number of accidents associated with the interchange areas. These occurrences are usually considerably more frequent than for segments of a through roadway; thus, the relative error involved in establishing a significant deviation from the statewide average is greatly reduced.

Case B-7: Complete or partial interchange lighting is considered to be warranted where the local governmental agency finds sufficient benefit in the forms of convenience, safety, policing, community promotion, public relations, etc., to pay an appreciable percentage of the cost of or wholly finance the installation, maintenance, and operation of the lighting facilities.

The warranting of interchange lighting by indirect benefits is implied in this case. It is apparent that the importance of these indirect benefits was not considered to be of great importance by the individuals who prepared the warrants.

Special Considerations: Where there is continuous freeway lighting, there should be complete interchange lighting. When continuous freeway lighting is warranted, but not initially installed, partial interchange lighting is considered to be justified under the continuous freeway lighting warrants A-1 or A-2. This would preclude the requirements of satisfying the partial interchange lighting warrants B-4 or B-5.

Where complete interchange lighting is warranted, but not initially fully installed, a partial lighting system which exceeds the normal partial installation in number of lighting units is considered to be justified.

Lighting of crossroad ramp terminals should be considered, regardless of traffic volumes, where the design requires the use of raised channelizing or divisional islands.

These special considerations seem to be logical and consistent with the needs of the driver. The last one, in effect, is the statement that would permit the designer to provide lighting for special geometric conditions that require it. However, the warranting of partial interchange lighting for these special considerations would probably be somewhat more difficult than with one of the more definitive warrants.

Warrants for Arterial Street Lighting

Warranting Conditions: It is not practical at this time to establish specific warrants for the installation of roadway lighting to satisfy all prevailing or anticipated conditions. In general, lighting is considered to be warranted for those locations where the respective governmental agencies concur that lighting will contribute substantially to the efficiency, safety, and comfort of vehicular and pedestrian traffic. Lighting should be provided for all major arterials in urbanized areas and for locations or sections of streets and highways where the ratio of night to day accident rates is high (say, higher than the statewide average for all similar locations) and a study indicates that lighting may be expected to significantly reduce the night accident rate. Where such determinations to install lighting have been made on the basis of experience and accident data under certain existing conditions, extrapolation should be made of these conclusions to other similar highway sections. The latter should include similar geometric layouts on which experience or accident data is not available and also highway sections where anticipated increase in vehicular and pedestrian traffic (either normal growth or sudden changes) will present problems within a few years. Lighting also should be considered at locations where abnormal or unusual weather conditions exist, such as the frequent occurrence of fog, ice, or snow. In other situations, lighting may be warranted where studies indicate that the resulting benefits, both tangible and intangible, are in the interest of the general public.

The general warrant statement can be divided into the 4 following areas of interest for purposes of analysis: population, major arterial streets, sections characterized by high accident rates, and weather conditions (fog, ice, and snow).

The first area is similar in content to the general warrant specified for freeways; it is stated that lighting is considered to be warranted if the respective governmental agencies agree that lighting is needed. Such a general statement cannot be applied on an objective basis because of the continual change in governmental representation.

The second area states that lighting is justified for all major arterial streets. This is somewhat more specific than the previous statement because a facility must be classified as a major arterial in order to meet the warrant. However, this has become a question of semantics. For example, a major arterial street near a central business district may have the characteristics of a local street once outside the central city. Thus, the classification referred to in the warranting condition is a functional, rather than an administrative, classification. This warrant could be a very valuable guide if judiciously applied. There can be little doubt that the lighting of major arterial streets serves to deter crime as well as improve driving conditions.

The third area deals with sections that have unusually high accident rates. The method of establishing the accident rate and the rate that, when exceeded, indicates a critical condition are not specified. The problem of evaluating accident exposure in urban areas is well known and documented in the literature. There still exists the possibility that a large number of accidents may be corrected by the addition of external illumination, and, if such trends are established, this should be considered as a warrant for lighting. The key is proper analysis of accident data, not comparison of accident rates. Both intersections and continuous illumination are included in this consideration.

The final area pertains to the frequency of adverse weather conditions (fog, rain, or snow and ice). Although some advantages are apparent from the standpoint of visibility, when external illumination is used during adverse weather conditions, the degree of improvement and the benefits associated with this improvement are questionable.

WARRANTS SUGGESTED BY KETVIRTIS

Ketvirtis (2) presents a set of conditions that warrants illumination for fixed sources, based on 3 classes of lighting circumstances:

1. Class I, Partial Illumination—Luminaires are located only at the critical decision points (beginning of acceleration and deceleration lanes, nose of channelization point, and so forth).
2. Class II, Intermediate Illumination—Luminaires are located as required by class I, with additional units on the ramps connecting to lighted roadways or at intersections with lighted highways.
3. Class III, Full Illumination—Full illumination refers to complete lighting of the facility, including all interchanges and at-grade intersections.

In addition to the 3 basic types of illumination, Ketvirtis utilizes a 4-level functional classification of the highway system. This classification includes the following: free-way and expressway, arterial, collector, and local.

In the following discussion of Ketvirtis' work (2), some of his warrants have been paraphrased.

Freeways and Expressways: Urban and Rural Main Lanes

Lighting is warranted when the ADT exceeds 40,000 vehicles per day (class III).

The selection of a specific volume level as a warrant for lighting the main lanes must be considered questionable. As the traffic volume increases, the need for information about the main lanes is reduced because the major driving cues come from the vehicle immediately preceding the subject vehicle. It is conceivable that increasing volume could require a greater number of lanes and thus create a greater degree of driver disorientation. The geometric condition, rather than the traffic volume, would logically be the warranting condition in this case.

Lighting is warranted where the ADT is less than 40,000, but one of the following conditions is met: the distance between the limits of illuminated interchanges is less than 1 mile; the section of the road is adjacent to high illumination levels such as shopping centers, theaters, or high-volume service roads (class III).

The first condition is apparently an attempt to account for the driver's discomfort by frequent changes from illuminated to unilluminated situations. The apparent assumption is that the interchanges are completely lighted. It is possible that class I illumination would not create any great degree of driver discomfort and, therefore, would not justify continuous illumination. The second condition is notably vague regarding the level of roadside illumination and the effect of spillover that must be considered in warranting conditions. The point is well taken that an increase in the level of roadside illumination will reduce the effectiveness of available light on the roadway; therefore, to maintain an equal level of effectiveness, additional illumination would have to be provided.

Freeways and Expressways: Urban Interchanges

Illumination is warranted at interchanges where the through traffic on either road is in excess of 25,000 ADT (class III).

It is difficult to understand how the interchange area, having a through-traffic density lower than that for the freeway main lanes, could warrant roadway lighting when it is not warranted for the main lanes. The requirements for the driving task certainly are not changed to the degree indicated by the reduction in the warranting condition.

Interchange illumination is warranted where traffic on any ramp branching off or connecting to an illuminated road is greater than 250 vehicles per hour (class II).

Roadways branching off from an illuminated roadway need illumination even for very light traffic volumes, whereas roadways connected to lighted facilities may not need any additional illumination in order to be effective. A value of 250 vehicles per hour may be too high for the former case and too low for the latter one.

Freeways and Expressways: Rural Interchanges

Rural interchange illumination is warranted where the through traffic on either road is in excess of 15,000 ADT (class II).

The use of any level of through traffic to warrant illumination seems a questionable practice, as previously noted.

Arterials: Main Lanes

Illumination is warranted where the distance between the limits of illuminated interchanges or intersections is less than ½ mile (class III).

The vague nature of "illuminated intersections" means that this warranting condition is almost boundless. Anything from a single incandescent bulb up to rather complete illumination of the intersection would seem to fit this definition. Some lower limit on the level of illumination should be established to make the warranting condition realistic.

Arterials: At-Grade Intersections

Illumination is warranted when the accident rate is high (3 or more per year) (class I or II).

The concept seems logical; however, the accidents that are to be included should be only those that could conceivably be corrected by illumination. Even then, the level (3 or more per year) seems very low. A better relation might be a ratio of night to day accident rates of 2:1 or greater.

Illumination is warranted at all signalized intersections (class I or II).

This warranting condition seems somewhat illogical. There does not appear to be a direct relation between the requirements for traffic signals and the need for external illumination of the intersection. However, an indirect relation may exist because of the complex nature of the vehicular movements in the intersection area. It is doubtful whether all signalized intersections warrant extensive illumination simply by virtue of warranting signalization.

Illumination is warranted at all channelized intersections (class I or II).

If the intent is toward channelization using raised curb for all intersections, the warranting condition seems appropriate.

Railroad Grade Crossings: Rural Areas

Illumination is warranted at rural crossings where the ADT is greater than 1,000 (class I).

The warranting condition does not account for exposure to trains. The warrant should probably be based on the product of the number of trains per day as well as the ADT level.

Tunnels and Underpasses

Tunnels up to 400 ft in length should have night illumination only when the associated road is illuminated.

It is assumed that the deflection angle is sufficiently small such that the tunnel end is apparent to the driver. Should this not be the situation, the warranting condition should include both day and night operation.

INTERNATIONAL RECOMMENDATIONS FOR THE INSTALLATION OF ROADWAY LIGHTING

The Commission Internationale de l'Eclairage (3) has established a general set of recommendations for the installation of fixed roadway lighting. These recommendations are composed of descriptive terms, rather than numerical values, and the values to be associated with each description were specifically left to national committees of each individual country. Although general in nature, the commission's recommendations could be considered as warrants.

On the basis of the nature of the road, the nature and amount of vehicular traffic, and the presence of pedestrians, it is possible to classify lighting installations envisioned by the present recommendations into three classes, comprising in all five subclasses.

The principal classes are as follows:

Class A: lighting for very important routes with rapid and dense traffic, where the only questions are the safety and the speed of the traffic and the comfort of the drivers.

Class B: lighting for roads with considerable vehicular and pedestrian traffic in which, in addition to the needs of drivers, the needs of pedestrians and shops and considerations of amenities and aesthetics are important.

Class C: lighting for residential roads having light local traffic.

Classes A and B have been divided into two subclasses according to the importance of the road.

By leaving to the individual countries the task of associating specific numerical values with the descriptive terms, the commission effectively obviated the problem of determining specific warranting conditions. It is apparent, however, that the commission is suggesting that lighting should be provided for all heavily traveled roadways, both rural and urban.

An examination of the warranting conditions of several European countries reveals the fact that few countries apply a volume warrant. Belgium has established an average daily traffic of 10,000 vehicles as warranting conditions for lighting on main roads. Belgium does not use this volume warrant on motorways (freeways); rather it uses an interchange spacing of less than 5 kilometers as a warranting condition. This minimum spacing (3.1 miles) is considerably more liberal than the 1½-mile criterion established by AASHO.

Several European countries apparently did not have specific roadway lighting warrants, whereas others utilized geometric conditions or economic returns as the method of establishing the warranting condition. For example, Holland specifies that continuous lighting is warranted in rural areas where 3 or more lanes are provided in one direction. England bases its justification on an economic analysis of the savings associated with an assumed 30 percent reduction in the night accident rate as compared to the cost of lighting the facility.

With regard to the geometric warrant being utilized in Holland, it is interesting to note that, for level-of-service C, a peak-hour factor of 0.83, a directional distribution factor of 0.6, and a peak-hour volume of 10 percent of the ADT, the design flow rate for 6 lanes would be 42,000 vehicles per day. This compares very favorably with the value recommended by Ketvirtis.

STATE HIGHWAY DEPARTMENT WARRANTING CONDITIONS

The warranting conditions recommended by AASHO are used, with minor variations, by most state highway departments. There are, however, some state highway departments that have developed their own warrants. Parts of one such set of warrants are discussed in the following paragraphs.

General: Contrary to traffic signals, properly designed highway illumination is not a liability if installed prematurely. Hence, the warrants for lighting are actually a method of establishing priorities based on available monies. If sufficient funds were available it would be desirable to illuminate continuously all urban highways and all rural highway intersections to reduce accidents and increase driver comfort.

This statement expresses the feeling of many professionals in the lighting field, i.e., that continuous illumination is always desirable but is sometimes unrealistic from an economic point of view. Thus, the warranting conditions are, in reality, an attempt to balance expenditures on roadway lighting and the funds available for such improvements.

The assumed reduction in accidents has been questioned, particularly when related to the main lanes of a traffic facility.

1. In rural areas only the intersections and pavement transitions may be illuminated.
2. In urban areas all intersections and pavement transitions shall have at least minimum illumination. Continuous illumination is desirable; however, it shall only be installed where the local agency has agreed to pay all maintenance and energy costs of lighting between intersections.

These qualifying statements are necessary in view of the extremely liberal warranting conditions specified by this state's policy.

Intersections

The minimum vehicular volume traffic signal warrant is met during any 1 hour of darkness on a typical day.

The interruption of continuous traffic signal warrant is met during any 1 hour of darkness on a typical day.

The minimum pedestrian volume traffic signal warrant is met during any 1 hour of darkness on a typical day.

Of 5 or more accidents at an intersection in a 12-month period, 50 percent or more are after-dark accidents.

These warranting conditions would appear to be rather liberal; however, there are no guidelines that would indicate how much reduction in the traffic signal warrants would be justified. It is apparent that, where there is sufficient conflict to justify the installation of traffic signals, lighting would be justified; but it could well be justified at a somewhat lower level. It might also be argued that illumination of the intersection area would make it more difficult to see an approaching vehicle because the contrast between the headlight illumination of the conflicting vehicle and the background would be reduced by the degree of fixed illumination.

The number of accidents does not reflect the fact that night accidents might not be eliminated by the installation of illumination. It may be reasonably assumed, however, that such accidents are in the minority and that an in-depth study to determine whether additional illumination might be effective would not be economical.

The MADT (Monthly Average Daily Traffic) for November, December, or January is at least 5,000 vehicles.

Five thousand vehicles per day is an extremely liberal volume warrant and would undoubtedly warrant illumination on all urban arterial streets and many collector streets. The area of illumination conditions previously presented would be vital for controlling the number of roadway sections to be lighted under this warrant.

The MADT for November, December, or January is 2,000 vehicles, and the 85th percentile speed is 40 mph or greater.

This warrant is very liberal, although it is doubtful that many urban facilities would have a 40-mph 85th percentile speed with an ADT below 5,000 vehicles per day.

Of 5 or more nonintersection accidents in a ¼-mile section of roadway, in a 12-month period, 50 percent or more are after-dark accidents.

This warrant seems reasonable, although arbitrary. The magnitude of the warrant seems consistent with the accident warrants for traffic signals. A logical question can be raised concerning the effectiveness of lighting for reducing accidents in nonintersection areas.

Signals

Whenever a traffic control signal or intersection beacon is installed, either at an intersection or mid-block, the area of conflict shall be illuminated (in the same manner as an intersection).

The lighting of signalized intersections may increase the target value of the intersection and thereby decrease the startle effect of the signal. Such an effect has not been established, however, and the warranting condition seems very liberal.

School Crossings

All officially designated and marked school crossings may be illuminated.

The word "may" seems to be the key word in the application of this warrant. School crosswalks that are utilized during the hours of darkness should be illuminated. The current trend toward split shifts in schools could result in children traveling to or from school during hours of darkness. Also, the expansion of adult classes during the evening hours could contribute to a need for illumination of school crosswalks.

System

Whenever the majority of intersections in a series on a through highway meets illumination warrants, the remaining intersections should be illuminated to avoid entrapment at the otherwise nonilluminated locations. In like manner, sections of nonilluminated roadway less than ½ mile in length between continuously illuminated sections should be continuously illuminated.

The system warrant seems to be reasonable, particularly because the intersection warrants can only be satisfied at major intersections, which would probably not include a majority of all intersections. For those cases in which the number of major intersections is a majority, illumination of the remaining intersections would probably be justified, and continuous illumination should be considered.

Transitions

All transitions from 2-lane roads to divided highways shall be illuminated. Lane-drops on multilane highways may be illuminated.

The lighting of all transitions is desirable but, through careful design, the need for illumination can be greatly reduced. The rather complex nature of the driving task in the transition areas cannot be denied, and fixed illumination could contribute substantially to the driver's orientation when approaching the transition. Nonetheless, the term "shall be" appears too restrictive.

Freeway Interchanges

All freeway interchanges shall be illuminated as follows: off-ramp gore, on-ramp merging area, through roadway just beyond gore (1 light), off-ramp just beyond gore (1 light), and loop ramps (continuously). Intersections of ramps with the surface street shall be considered for lighting if the warrants for intersection lighting are met; if one ramp intersection is illuminated, all ramp intersections at the interchange shall be illuminated.

The freeway interchange warrant is consistent with the safety lighting concept now prevalent throughout the country; however, local rural interchanges with very light traffic may not justify the installation of safety lighting from an economic point of view. It can be argued that, if sufficient turning traffic exists to justify an interchange, sufficient justification exists for safety lighting because the driving task complexity at interchanges is as great as that that the driver will face on the freeway.

CONCLUSIONS

Review of the roadway lighting warrants currently in use reveals that 3 broad policies are being employed in establishing roadway illumination warrants. These policies are as follows:

1. Minimize sites warranting lighting—Fixed illumination is desirable on all classes of roadways, but, because of limited available funds, only a few sites should be warranted so as to have a firm basis for refusing to light a section of roadway. Thus, the warranting conditions should be set very high.
2. Maximize sites warranting lighting—Fixed illumination is desirable on all classes of roadways, and available funds will provide for illumination on relatively few. In order 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.
3. Act only where economically justified—Fixed illumination should be provided only at those points on the roadway that are complex, from a geometric point of view, because fixed illumination cannot be economically justified for most sections of roadway.

It is also apparent that virtually all 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 a 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 a set of warrants that is based on 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; therefore, the functional value of the warrant concept may well have been lost. The warrants appear to be utilized more for establishing the actual governmental agencies that will participate in the financing of the lighting system than for establishing the minimum conditions for which illumination can be expected to be effective.

PROPOSED FRAMEWORK FOR WARRANTS

Existing warrants do not deal directly with the principal function of the fixed lighting system, that is, to facilitate visual communication on traffic facilities through improved night visibility. There is a need to develop a more rational set of warrants based on driver informational needs as related to the roadway, traffic, and environmental conditions of the traffic facility. Such a set of warrants is being proposed in conjunction with a research project within the National Cooperative Highway Research Program (NCHRP). In fact, it is proposed that the total design process—warrants, guidelines, priorities, benefits, and cost-effectiveness—be developed around one common framework or concept.

This proposed framework for the total design process consists of a numerical rating system that ties the total process together in one package. Beginning with warrants, the features of the facility (geometric, operational, and environmental), which constitute the visual information needed by the driver, are rated numerically on a scale (1 to 5) such that the magnitude of the sum of the ratings or points of each of the features is an indicator of the severity of the visual communication problems. When this sum is compared to a number of points representing acceptable conditions, the warranting condition is established (e.g., 145 points > 95 points as a minimum value).

The relative priority of installing lighting is established by setting the sum of the rating points in a ratio with the minimum number of points to justify lighting (e.g., $145/95 = 1.55$). This priority index, when compared to other projects, indicates the relative severity in provision of driver informational needs with the installation of fixed lighting.

The guidelines for design, specifically the level of illumination, are determined by using the ratio developed for priorities as a multiplier of the minimum average illumination value as recommended by the Illuminating Engineering Society (IES). For example, the IES recommendation of 0.6 hfc for freeways would be increased by a factor of 1.55 if the previous example was applied.

The benefits are reflected in the solution of visual communication problems through fixed lighting. It is implicit that reducing the numerical rating of a given facility through the installation of fixed lighting results in benefits through an improved night driving situation.

Conventional methods use a monetary value for analysis of the effectiveness of a project. A method is established for cost-effectiveness analyses where supplying informational needs is a measurable effectiveness quantity.

The warrants package provides a logical framework for the total design process for fixed lighting. It should be recognized that the concept reported to NCHRP is tentative, and it has been proposed that the package be tested by a selected group of agencies for a period of time to ascertain its value to the profession and to identify needed modifications for practical application.

REFERENCES

1. An Informational Guide for Roadway Lighting. American Assn. of State Highway Officials, Washington, D. C., 1969, 22 pp.
2. Ketvirtis, A. Highway Lighting Engineering. Foundation of Canada Engineering Corporation, Toronto, 1967, 344 pp.
3. International Recommendations for the Installation of Roadway Lighting. Commission Internationale de l'Eclairage.

DISCUSSION

W. H. Edman

With the advent of the automobile, "public lighting" took on a new meaning. To my knowledge, the first research of practical significance was initiated in 1910 to 1913 by Sweet. The research was conducted under the auspices of the Railroad Warehouse Commission at Madison, Wisconsin, and dealt with measurements of disability glare. Following this, an extensive research project was conducted in Philadelphia in 1914 under the leadership of Preston Millar. As a result of these studies, there was developed the concept of seeing by silhouette, reverse silhouette, glint, and shadow. The first use of the term "revealing power" of a street lighting system was also conceived, and this work was further added to by Waldram of England in the late 1930s.

No professional organized group existed until the IES Roadway Lighting Committee was formed at the request of the International Congress of Illumination and the Bureau of Standards. This was a request made in 1925 to prepare a circular on street lighting. This first report on principles of street lighting appeared in 1927 followed by the first code in 1930. Subsequently, there have been revisions made in 1935, 1937, 1940, 1945, 1953, 1963, and 1972. The first American Standard Practice appeared in 1947.

The first major installation that can be associated with the results of research was made in Milwaukee, Wisconsin, shortly before World War I. It was the first fully planned city street lighting system. It was then looked on as too radical with respect to the high mounting heights of 30 ft, first fully controlled light distributions, and other innovations.

The principal activity in street lighting during the 1920s was developing white-way lighting for the business streets. Little attention was paid to residential and traffic streets. In the 1930s began the era of traffic safety lighting after the number of motor vehicle accidents began to soar, especially night accidents.

This resulted in the development of more efficient luminaires with controlled distribution and the introduction of high-pressure mercury and low-pressure sodium sources. During World War II all progress was stopped. After World War II there began a slow conversion to the use of mercury sources. A number of utilities were slow in accepting this efficient source, but its acceptance gathered momentum in the late 1950s with an accelerating pace in the 1960s.

With regard to research, the newly formed Illuminating Engineering Research Institute (IERI) in 1944 requested subjects for roadway lighting research. However, interior lighting received priority at that time. About the mid-1950s, the Night Visibility Committee of the Highway Research Board, under the leadership of Burton Marsh, developed a program for research on highway lighting. The first major project was conducted on the Connecticut Turnpike, and subsequent to that both IERI-funded and federal-funded research projects have been undertaken and are currently under active pursuit.

D. Fischer

I should like to make some comments on the paper by Rowan. These comments are of course mainly based on the situation as it exists in Europe.

Rowan mentions the following as the objectives of street and highway lighting: crime reduction, civic improvement, and traffic safety. I should like to add three more objectives: visual comfort, increased road capacity at night, and optical guidance.

Street lighting installations of medium height and adequate quality already reduce the probability of traffic accidents to such a level that further improvement in the lighting can hardly be expected to give any further significant reduction in the number of accidents.

However, investigations and assessments of practical installations show that street lighting can be improved beyond this level to the advantage of the road user by ensuring a greater degree of visual comfort to the driver. I think that visual comfort on the road should not be regarded as a luxury but as a means of allowing the road user to play his part in the traffic without strain. Additionally, improved visual comfort is likely to reduce driver fatigue and thus add to general traffic safety.

Only under comfortable seeing conditions can one expect a smooth flow of traffic, even on a very busy road, that allows full advantage to be taken of the traffic capacity of the road. In many countries the rush hour for road traffic occurs during the hours of darkness during much of the year. Seen from this point of view, the requirements for good road lighting are not merely to offer the possibility of safe driving by ensuring easy and reliable perception, but also to bring the car-carrying capacity of the road at night up to the same level as was planned for it during the day. Road capacity is already a very pressing problem on a large number of roads leading in and out of large towns and cities. In view of the enormous sums of money that are being invested in the construction of new traffic routes, the problem of good road lighting is one of great economic importance. This is the reason that, in Europe, it is thought that traffic-volume requirements alone can justify the installation of fixed road lighting.

The third objective I should like to add is the need for optical guidance. Good correspondence and harmony between the run of the road and the line of the lighting helps the optical guidance of drivers, especially in fast traffic on main thoroughfares, and thus contributes to their safety and orientation. This is especially the case for roads having many curves or where there are rather short distances between interchanges on motorways.

Optical guidance at complex traffic junctions cannot, however, be achieved with conventional street lighting installations. A better solution for these areas is thought

to be the simulation of daylight by means of a high mast installation, lighting the whole complex to a more or less uniform illuminance level.

Another means of achieving optical guidance with a street lighting installation is to use different lamp colors for through roads and for local arteries.

J. Stuart Franklin

Warrants, as presently written, appear to deal primarily with the location of lighting. They say little about the quantity or quality of the lighting that will be installed.

Existing codes and guides for street and highway lighting specify quantity (levels and uniformity), leaving the definitions of quality somewhat vague.

Recently, some cities and municipalities have been enacting ordinances restricting the spill light from all types of lighting equipment. Some of these are very restrictive in terms of light intensity and luminance.

If the quantity of lighting is specified on the national and international levels and the quality is spelled out on the local level, nothing but frustration and conflict will result.

A. Ketvirtis

In his paper, Rowan is critical of some major conditions that warrant illumination. He particularly objects to traffic volume being used as a measure of indicating the need for roadway illumination. In my opinion, although other traffic system characteristics should be taken into consideration, volume is one of the most important factors in establishing priorities for highway illumination. Other factors that should be included in these considerations are roadway geometry, accident frequency, presence of pedestrians, road geographic location, and visual distractions. In recent reviews of existing warrants, some traffic engineers are advocating that traffic density be used as a supplementary factor to traffic volume.

It should be remembered that warrants are used mainly by traffic engineers and highway administrators for objective allocation of public funds. Therefore it is imperative that they include the following characteristics:

1. As a general guide for warrant definitions, a traffic facility should be regarded as an integrated roadway system emphasizing intended levels of service;
2. For easier use of the warrants, major traffic-system characteristics such as volume, geometry, geographic location, and accident rate should be taken into account;
3. The warrants should need a minimum of subjective interpretation—any ambiguity would destroy them; and
4. Complicated calculations and lengthy procedures to arrive at warranting conditions should be avoided.

Richard E. Stark

Current warrants use traffic volume as the primary determinant in installing roadway lighting. A road having poor geometric design and experiencing low traffic volumes may not warrant lighting because the number of events and conflicts are few. On the other hand, a roadway having perfect geometry can experience events that are not related to geometrics but to volume. As volume increases, events such as vehicle breakdowns, multiple-vehicle accidents, debris falling from trailers and trucks, and erratic pedestrian occurrences all begin to increase and occur on a regular basis. Higher volume usually means higher numbers of pedestrians. These are motorists who have left their vehicles because of disabilities and accidents as well as occasional hitchhikers. In 1 year approximately one-half of the fatalities that occurred on the Chicago expressway system involved pedestrians. It is my thought that volume should be included along with operational factors.