AN ASSESSMENT OF THE NEED FOR CHANGES IN VIRGINIA LAW CONCERNING HEADLAMP USAGE

by

Edward J. Rinalducci
Faculty Research Psychologist

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

An evaluation was made of the need for changes in Virginia law concerning headlamp usage during periods of dusk and dawn and at times of limited visibility. At the present time motorists are required to turn on the headlamps of their vehicles one-half hour after sunset and to leave them on until one-half hour before sunrise. In addition, headlamps are required whenever visibility at 1524 m (500 ft.) is not adequate for driving. The analysis included a review of the pertinent literature, photometric measurements of the illumination available at dusk and dawn, and a survey of the headlamp usage laws of all states in the U. S.

The review of the literature combined with the photometric measurements indicated that there should be difficulties in seeing and being seen during the dusk/dawn period. The survey of headlamp usage laws indicated that 66% of the states had the same requirements as Virginia for the dusk/dawn period while 54% had the same requirements for usage under conditions of limited visibility. However, the survey suggested precedents for changes in the Virginia laws.

Based on these results it is suggested that the following changes in headlamp usage be made: 1) headlamps be turned on at visible sunset and be left on until visible sunrise; and 2) headlamps be turned on whenever there is precipitation (rain, snow, etc.) or when visibility is not adequate for 1,524 m (500 ft.). It is felt that these changes should improve the ability of the motorist to see and to be seen and thereby contribute to highway safety.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

Findings

The results of this investigation are summarized in the paragraphs below.

Literature Review -

The factors reviewed included the role of vision in highway safety and the relevant aspects of the visual environment at dusk and dawn, conspicuity or vehicle noticeability, headlighting and glare, and the age of the motorist. The review indicated that it should be difficult for a motorist to see or be seen during the dusk/dawn period. Previous research has suggested that the average roadway illuminance for adequate seeing be on the order of 2 fc (22 lx).

Illuminance Measurements -

Values of illuminance obtained by this investigator and other researchers one-half hour after sunset and before sunrise were found to be on the order of 0.06 fc (0.6 lx), while illuminance levels at visible sunrise and sunset were well above the recommended 2 fc (22 lx) level.

Survey of Headlamp Usage Laws -

A survey of headlamp usage laws for the various states indicated that the majority of states had laws similar to those of Virginia. However, a number of states (22%) required headlamps to be turned on at visible sunset and to be left on until visible sunrise.

Recommendations

Based on the findings of this study, the following recommendations are made.

1. Headlamps should be turned on at the time of visible sunset and be left on until visible sunrise. There are several advantages to this recommendation: illuminance levels at these times are well above the 2 fc (22 lx) level; the use of low-beam headlamps increases the conspicuity or noticeability of a vehicle; the older driver would be under less of a visual handicap; and the enforcement of this requirement would be easier for the law enforcement officer and its obeyance easier for the driver. In addition, there is precedent in the headlamp usage laws of other states.

2. Headlamps should be used when visibility at 1,524 m (500 ft.) is not adequate for driving, and whenever there is any precipitation. This would permit a safe stopping distance and ensure noticeability and placement of vehicles on the highway.

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INTRODUCTION

It has been noted, through a public complaint by a driver new to Virginia traffic conditions, that Virginia drivers appear to be less inclined to use their headlamps early in the dusk/dawn period than are motorists in other states. This inclination towards less use may be in part a reflection of the Virginia laws on headlamp usage. At the present time drivers are required to have their headlights on 30 minutes after sunset and up to 30 minutes prior to sunrise. In addition, headlamps are required whenever visibility at 1,524 m (500 ft) is not adequate for driving. Late headlamp usage may represent a problem in highway safety, and, to the extent this is true, it may be that the laws regarding headlamp usage need amending.

The objective of the literature review discussed below was to examine the visual requirements of the motorist at dusk and dawn and at times of limited visibility. It was expected that a review of the pertinent literature would also be useful in making recommendations concerning headlamp usage and in establishing objective criteria for those recommendations.

The two sections following the literature review examine, respectively, the ambient illuminance levels available at dusk and dawn and the results of a survey of headlamp usage laws of the various states. It was thought that ambient illuminance levels would provide some indication as to whether or not adequate light is available for seeing during the dusk/dawn period and when it is available. The survey of state laws was made to determine precedents for changes in the Virginia laws. The final section of the report presents conclusions and recommendations based on the findings of the study.

LITERATURE REVIEW

Visual Environment and Problems at Dusk and Dawn

In general, a review of the literature indicated that there were only a few studies dealing specifically with the visual needs for adequate seeing, visual problems, and highway safety during the dusk/dawn period. The first task, however, was to define that period referred to as dusk and dawn. Twilight is the term often used to refer to the dusk or dawn periods which occur around sunrise or sunset (Admiralty Manual of Navigation, 1960). Essentially, twilight is said to be that period during which the sun is just below the horizon, but the observer is still able to receive light through scattering and reflection in the upper atmosphere. There are three common terms referring to twilight: Civil Twilight; Nautical Twilight; and Astronomical Twilight. Each one is said to end or begin depending upon the location of the sun's center below the horizon. Civil Twilight ends or begins when the sun's center is 6° below the horizon. This is roughly the time when the horizon appears to be less distinct or clear than it is during daylight hours. Nautical Twilight ends or begins when the sun's center is 12° below the horizon, and Astronomical Twilight ends or begins when the sun's center is 18° below the horizon. Morning twilight, or what is commonly referred to as dawn, therefore, begins when the sun's center is at the appropriate depression (for Civil, Nautical, or Astronomical Twilight) below the horizon and continues until visible sunrise. Evening twilight, or dusk, begins at visible sunset and lasts until the sun's center reaches the appropriate depression. The times of visible sunrise and sunset and the duration of the twilight period depend upon such variables as latitude, longitude, and the time of the year. As the three types of twilight differ depending upon the location of the sun's center below the horizon, the period of twilight would be briefest for Civil Twilight and longest for Astronomical Twilight, with Nautical Twilight being intermediate. However, Box (1971), in a study examining the relationship between freeway accidents and illumination, noted that Civil Twilight occurs between 30 to 40 minutes before or after sunrise or sunset (dawn or dusk, respectively) and is close to that point in time when natural daylight is almost indiscernable. Also, light levels were observed by Box to change rapidly during these periods. Unless otherwise noted, Civil Twilight will be used in this report to define dusk or dawn.

Two basic considerations relate to the role of vision in highway safety. They are the extent to which the driver can see, and the extent to which he can be seen (Pedler 1963). Therefore, vision is perhaps the most important of many factors which may affect driver performance. There are many aspects of vision and the visual environment of the highway which may contribute to driver performance and safety (Allen 1970; Burg 1971; Davison 1978; Henderson and Burg 1975; Kaufman 1972; Richards 1967). These factors can be divided into two separate but related categories: physiological and psychological factors which depend to some extent on the functioning of visual sensory processes, and physical factors which describe the characteristics of the visual tasks in driving and the environment for seeing. The first category includes such factors as acuity (both static and dynamic), adaptation, the relative sensitivity of various retinal areas, the field of view (central vs. peripheral vision), perception of depth or distance, glare (disability and discomfort), and conspicuity (attention-getting value of a light or signal). Other physiological variables such as age, fatigue, state of health, drugs, etc. would also have effects on factors in the first category. The second category would include the amounts and distribution of available light, the contrast, size, and color of an object (obstacle, car, pedestrian, sign, etc.), and fog and atmospheric conditions.

Most authors agree that at dusk or dawn seeing becomes difficult for the driver and visibility is reduced (Allen 1970; Allen and Carter 1964; Pedler 1963; Richards 1967). One problem is related to the situation wherein the light from the sky is still intense enough at twilight to prevent the eye from adapting (or increasing its sensitivity) to a level sufficient to use the small amounts of light being reflected from the roadway. With nightfall the eye is actually capable of increasing its sensitivity. Also cues to depth are decreased under dim illumination and thus handicap the judgment of distance, which is important to fixing the position of vehicles on the highway, and estimating their velocity is impaired. Stereoscopic vision depends upon disparate images being presented to the two eyes. This information is sent to the brain where it is interpreted in terms of distance from the observer. Richards (1967) indicates that at night stereoscopic vision is reduced, but that at twilight the impression of depth is increased. Therefore, at dusk and dawn objects would appear further away than they really are. The effect seems to be greater for older observers (Sachsenweger 1956). With a reduction in available light at dusk and dawn there is also a loss of color information. Not only are darker colored automobiles more difficult to see than in daylight but the loss of color contrast contributes to the overall reduction in the visibility of objects on the roadway (Pedler 1963).

Allen (1970) has noted that headlights should probably be turned on whenever the sun is lower than about 15° from the horizon. He suggests, therefore, that they should be turned on 1 hour before sunset and not turned off until 1 hour after sunrise. This practice would assist motorists in seeing oncoming cars against a setting or rising sun. The rationale for setting ideal hours of operation for headlamps is basically twofold. The first goal is that of increasing the ability of the driver to see under twilight conditions, and this involves increasing visibility. The second goal is one of increasing the probability of being seen by others. The latter is sometimes referred to as conspicuity, or noticeability. Headlamps used as Allen suggests would aid in placing vehicles on the highway.

Finally, Attwood (1975) indicates that the use of headlights improves the detectability of oncoming vehicles at dusk and dawn and during periods of low ambient illumination. In a recent study (Attwood 1979) addressing the nonuniform use of headlights around dusk and dawn, he concludes that there can be a reduction in visibility caused by veiling effects of automobile headlights. That is, oncoming unlit vehicles can be masked by the low-beam headlights of surrounding vehicles traveling in the same direction. He recommends that to reduce this problem consideration be given to extending the lights-on period from one-half hour before sunset to one-half hour after sunrise. In this way the detectability of each vehicle is increased despite masking effects.

Subsequent sections of this review will examine those factors most pertinent to seeing and being seen at twilight or under conditions of reduced visibility.

Visibility and Highway Driving

Visibility has been defined as "the quality or state of being perceivable by the eye" (Kaufman 1972). It is an important factor in driver performance and highway safety, and is concerned with the extent to which a motorist can see an object on the roadway. Research on visibility has traditionally involved visual tasks carried out under interior lighting conditions (e.g. inspection of a product). More recently, however, similar methods have been applied to the highway environment, especially with regard to nighttime driving and roadway lighting specifications. An actual driving situation might involve a motorist driving along a roadway during nighttime or at twilight (i.e. during periods of reduced ambient illumination). The motorist would require sufficient illumination in order to see and avoid an obstacle on the road or a pedestrian. An obstacle or a pedestrian would have a certain contrast against the roadway. The objective of research on visibility has been to prescribe lighting levels necessary for the adequate seeing of targets of a given contrast with their backgrounds. Consideration is given below to research on visibility done both in the laboratory and in the field situation.

The research of H. R. and O. M. Blackwell of Ohio State University has played a prominent role in the specification of lighting under both interior and roadway conditions (Blackwell 1959, 1961, 1964, 1972; Blackwell and Blackwell 1971; 1977; Blackwell, Schwab, and Pritchard 1964). Basically, they are interested in determining "how much visual performance the lighting system will provide" (Blackwell 1974).

The Blackwells have carried their research in the laboratory on the basic parameters of visibility to the measurement of visual tasks in the field. A visibility reference function was originally derived based on the detection of a luminous 4-minute disk of 1/5 second exposure. The obtained function showed target contrast[1] vs. background luminance.[2] This threshold function was designated VL 1, where VL refers to the visibility level. When appropriate adjustments were made to take account of such difference as knowing and not knowing where the target will appear, moving vs. stationary targets, and 99% vs. 50% probability of detection, a curve known as VL 8 was produced (here task visibility exceeded threshold visibility by a factor of 8). The VL 8 curve is often used as the reference lighting criterion to determine values of illumination required for threshold contrast for different tasks. The visibility of a visual task in the field is then found by using a contrast-reducing visibility meter (Blackwell's Visual Task Evaluator, VTE). The contrast of the target is reduced optically until it reaches a borderline between visibility and invisibility. The VTE permits the reduction of the contrast of a real-world complex target to threshold. This reduction allows the establishment of the task's visibility relative to the laboratory data, and can be used in turn to prescribe the required task luminance.

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[1] The relationship between the luminance of an object and its immediate background. Often expressed as

$$C = \left| L_1 - L_2/L_2 \right|$$

here C is contrast, L_1 is the luminance of the object and L_2 is the luminance of the background. This definition permits C to take any value from zero to infinity.

[2] Refers to the intensity of a light from a light source or a reflecting surface toward the eye. Measured in fL or cd/m^2. Illuminance refers to the light flux falling onto a surface and is measured in fc or lx. Luminance and illuminance are related to each other by the reflectance of the illuminated surface. For example, if an object or surface that reflects 20% of the light falling on it is illuminated by 10 fc (107.6 lx), its luminance will be 2 fL (6.8 cd/m^2).

More recently, the Blackwells (Blackwell 1974; Blackwell and Blackwell 1977; Blackwell, Schwab, and Pritchard 1968) have extended the same visibility procedures to roadway lighting problems. Here what is termed the effective visibility level (VL_{eff}) is determined by taking into account the effects of spatial patterns of lighting (or nonuniformities), which is accomplished by determining the equivalent contrast with the visibility meter (VTE). The equivalent contrast is used to derive the appropriate visibility level, which in turn is multiplied by a disability glare factor[3] and a transient adaptation factor.[4] The product is the effective visibility level, which can be employed to help specify illumination on the highway.

Recently, Hills (1975a, 1975b, 1976) has also developed a model employing luminance increment-visual area night driving characteristics for predicting visibility under varying conditions of background and veiling glare luminances. He was able to demonstrate that this model could describe satisfactorily the visibilities of pedestrian manikins, disc objects, and taillights under conditions of no road lighting and no-glare night driving conditions.

Gallagher and his associates at the Franklin Institute Research Laboratories (Gallagher 1975; Gallagher and Meguire 1974, 1975) have developed procedures which attempt to combine the theoretical framework of the Blackwells with driver performance measures taken in the field. The driver performance measures consisted of a proportion of instances in which drivers were able to avoid hitting obstacles on the roadway or see them sufficiently far enough ahead to slow down safely. The critical measure was the time separation between the vehicle and the target when an evasive maneuver or a slowing down by the driver was initiated. Targets consisted of the bottom portion of a standard traffic cone painted with a low reflectance gray paint. These targets were placed at 50-ft (15-m) intervals on a street in Philadelphia.

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[3] This factor is related to the glare produced at the light source as well as that at other reflective sources in the field of view. It is the veiling luminance produced in the eye by the surrounding luminance field.

[4] This factor refers to the temporary loss in contrast sensitivity produced when the observer changes his fixation from the task to surroundings of different luminances and back to the task again when normal scanning by the eyes occurs. The measurement procedure and treatment of the data of this parameter are presently being investigated.

Several visibility measures (including contrast, effective visibility level, and the visibility index[5]) were examined in relation to driver performance measures. The effective intensity level is determined by using a measure of equivalent contrast obtained with a visibility meter. The visibility index (VI), on the other hand, employs a measure of photometric contrast obtained by physically measuring target and background luminances with a photometer. As the magnitude of the contrast, visibility level, and visibility index increased so did the time-to-target and the design velocity of the roadway. All of these measures are related to the specification of roadway lighting.

In an earlier and related study Gallagher, Janoff, and Farber (1974) examined the effects of illumination on driver behavior. There were three categories of vision-dependent tasks: 1) attentional demand; 2) target detection; and 3) gap acceptance. Data obtained from the last two tasks are of particular relevance in specifying adequate roadway illumination. The optimal street lighting for these tasks fell in a range between 0.4 to 2.5 fc (4.3 to 26.9 lx) with the actual optimal value being slightly greater than 1.0 fc (10.76 lx).

Matanzo and Rockwell (1967) conducted a study aimed at relating nighttime driver performance to levels of "visual degradation" (i.e. overall luminance levels of 4.857, 2.497, 0.701, and 0.156 fL [16.640, 8.555,2.402, and 0.534 cd/m^2]). The visual degradation caused test drivers to slow down and position their vehicle farther from the shoulder of the road.

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[5] Visibility index of a target is determined by

$$VI = \frac{C(RCS_{Lb})}{5.74} \times DGF,$$

where C = physical or photometric contrast = $\left| L_1 - L_2/L_2 \right|$;

RCS_{Lb} = relative contrast sensitivity for drivers adapted to a luminance level equal to Lb; and

DGF = disability glare factor.

Effective visibility level is the same expression but equivalent contrast is used instead of photometric contrast. (Gallagher and Meguire 1974, 1975).

Fischer (1975) describes the European approach to roadway lighting as one which employs a "standard critical task" defined in terms of the smallest obstacle that might cause an accident. This standard obstacle has an 8 X 8 in. (20 X 20 cm) vertical surface area and must be clearly visible at 330 ft (100 m). Investigations into required roadway lighting levels with respect to this task resulted in a required average road luminance of at least 0.6 fL (2 cd/m^2). An average luminance on the road of 0.6 fL (2 cd/m^2) would require an average illumination of 2.3 to 2.8 fc (25 to 30 lx). Recent recommendations presented in the American National Standard Practice for Roadway Lighting and sponsored by the Illuminating Engineering Society (1977) are in line with the maintained average roadway luminances recommended by the CIE (1965) and Fischer (1975) for major roads and expressways: 0.15 fL (0.51 cd/m^2) to 0.6 fL (2.0 cd/m^2). However, the IES (1977) recommendations for average roadway illuminance levels vary somewhat for major roads vs. freeways vs. expressways. These values range from a high of 2 fc (22 lx) to a low of 0.6 fc (6 lx). There is some controversy over whether to specify lighting in terms of luminance vs. illuminance (King 1972) due, in part, to variations in the reflectivity of the road pavement, which may be quite great. However, there does appear to be some agreement that the average roadway luminance should be about 0.6 fL (2.0 cd/m^2) and the average illuminance should be in the neighborhood of 2 fc (22 lx).

Box (1971) has examined the relationship between illuminance and freeway accidents at several locations including Toronto, Denver, Chicago, Atlanta, Dallas, and Phoenix. Some of the conclusions drawn by Box seem to have relevance to dusk/dawn headlamp usage. First, he found that there were 40% less accidents of all types at night on lighted as opposed to unlighted freeways and 52% less fatal and injury-producing accidents. Second, about 25% of urban freeway traffic occurs at night. Third, the moment of "darkness" (the level of ambient illumination at which streetlighting becomes effective) occurs about 15 minutes before sunrise or 15 minutes after sunset. Fourth, the data did not allow specification of an optimum illumination level (the range of illumination levels examined was 0.3 to 1.5 fc (3.23 to 16.14 lx). There was a tendency for the freeways with the lower range (0.3 to 0.6 fc [3.23 to 6.46 lx]) to show the best ratio of night/day accidents. However, Box indicates that the higher levels may create a deceptively safe environment. In addition, Brass and Trosper (1957) have pointed out that "Most drivers confronted with poor conditions for visibility will drive with caution and with reduced speed". Following this logic it could be argued that the lower accidents rate may indicate a problem. In spite of this, however, accidents were lower on the lighted than on the unlighted freeways. Finally, drivers of age 40 and above had 27% to 28% of the accidents on urban freeways. In the lighted section of the freeway, 18% of the accidents involving drivers age 40 and over occurred at night. In the unlighted section, 29% of the accidents for drivers 40 and over occurred at night. Thus age is an important factor in the relationship between illumination and freeway accidents.

In summary, the preceding discussion on visibility has concerned those factors which affect the driver's ability to see an obstacle on the roadway. The emphasis has been placed on night driving conditions as they more nearly reflect those found during the dusk/dawn period than do day conditions. The Blackwells have developed an elaborate theoretical framework and procedure for determining the visibility of a potential obstacle, and which can aid in prescribing adequate lighting levels for good visual performance. Their procedures, however, often require elaborate equipment which may not be readily accessible (e.g. telephometer, visibility meter, and glare lens for the telephometer to determine disability glare). Gallagher and his associates, however, have been able to take the methods of the Blackwells and combine them with driver performance measures. Their research and that of Fischer and the European lighting investigators seem to find agreement with CIE and IES roadway lighting recommendations. Box has been able to show that there were fewer freeway accidents on lighted roads than on unlighted roads but that the relationship was a complex one. His work also demonstrated the importance of age in specifying lighting for roadways. Those drivers age 40 and above constitute a large portion of the motoring public, and their visual capabilities must be taken into account. Other approaches to determining visibility and studies of driver performance were also briefly discussed.

Conspicuity of Vehicles

In addition to being able to see an obstacle on the roadway, those factors relating to the probability of being seen are important. The capability for being seen may loosely be referred to as conspicuity, which can be defined as the attention-getting value of a light or signal (Holmes 1971; Kaufman 1972). Vehicle headlamps (and to some extent running or parking lights) should aid not only in helping a vehicle to be seen but also in placing it on the highway. Headlights can also be used to estimate distances between oncoming vehicles and one's own vehicle. At a distance the two headlights cannot be resolved, but as the vehicle approaches they separate and the changing visual angle between the lights provides a cue for distance (Richards 1967).

Horberg (1975) has investigated vehicle conspicuity (sometimes called noticeability) using three running light intensities. The results indicated that there was no increase in conspicuity until the ambient sky illumination was down to about 93 fc (1,000 lx). Very small differences were found between the different light intensities. A second study dealt with the effects of running lights on distance judgments. Again, no effects of light intensity were found, but there was a tendency to underestimate the distance to a vehicle with running lights. Horber suggests that this underestimation may provide a margin of safety to oncoming vehicles since the subjective distance is less than the objective one.

Gallagher et al. (1974), on the other hand, report an overestimation of vehicle distance when using parking lights. They report that the visual tasks of seeing and being seen were optimized at very similar illumination conditions (0.4 to 4.5 fc [4.3 to 48.4 lx]). The safest and least variable separation distance estimates were obtained at 1 fc (10.76 lx) ambient illumination and low beams on an approaching vehicle. A high-beam headlighting mode was found to be unsatisfactory due to glare which confused the viewer and reduced the estimated separation distance.

Cantilli (1969) has also shown that the use of running lights in daylight can reduce the number of accidents. Similarly, King and Finch (1969) evaluated the use of daytime running lights (in this case they were not parking lights, but a special running light mounted in the middle and front of the car). They concluded that the daytime visibility of a vehicle can be improved by the addition of a running light. They provided recommendations for the intensity and size of such a light. They also noted that in the case of dark-colored vehicles, the greatest visibility problem occurred under low ambient light levels such as those found at sunrise, sunset, and under heavily overcast weather conditions. Under low ambient light levels, the light-colored vehicle has an advantage, but it may also present a problem with very high background luminances such as might be encountered on bright sunny days.

Considerable interest has been directed to the use of lights (headlights, taillights, and running lights) as a means to enhance the conspicuity, or noticeability, of motorcycles during the daytime. It is believed that many accidents between motorcycles and other vehicles occur because the operators of the other vehicles do not see the motorcycles. A number of states have passed laws requiring the use of headlights on motorcycles during the day. Cassel and Janoff (1971) reported that the use of motorcycle headlights during the day significantly increased the noticeability of the motorcycle by other motorists. The effectiveness of headlight use was found to be greater in cloudy than in clear weather. In rearlight experiments, red taillights were found to be less effective than dual amber taillights in increasing noticeability. Janoff and Cassel (1971a), in another series of experiments, also showed that motorcycles operating with headlights on during the day caused other vehicle drivers to notice them sooner and at greater distances. Similar experiments done more recently by Ramsey and Brinkley (1977) examined the use of visual signal warning devices to increase noticeability. They found that a flashing amber light mounted on the front fender of the motorcycle increased noticeability by more than 300%. Woltman and Austin (1973) also evaluated the use of flourescent materials on the motorcycle and the motorcycle driver to increase their visibility during the day and the night.

Janoff and Cassel (1971b) noted that in four states (Indiana, Oregon, Montana, and Wisconsin)with laws requiring the daytime use of headlights on motorcycles there had been a significant decrease (3.8%) in motorcycle accidents. However, more recently Kendall (1978a, 1978b) has concluded after examining similar accident statistics in these states in more detail and in the state of Illinois, which passed a light-on law for motorcycles in 1970, that headlights are not an effective countermeasure. Indeed, according to Kendall the accident rate is directly related to the number of motorcycle registrations. He also noted that due to the nature of the motorcycle's electrical system, many could not physically comply with a mandatory light-on law.

In summary, it would appear that in spite of Kendall's findings the use of headlights and running lights does increase the conspicuity, or noticeability, of vehicles, and allows the placement of the vehicle on the highway and the judgment of distances of oncoming vehicles. Based on the results of Gallagher et al. (1974) distance judgments would seem to be more accurate with the use of headlights (low beams) than with parking lights.

Glare and Headlighting

The subject of glare naturally arises when one considers the use of headlamps under dusk/dawn light conditions or conditions of reduced visibility. It is possible that glare from headlamps might be a contributing factor in night driving accidents (Richards 1967).

In general, glare can be defined as the sensation produced by a light source within the visual field which is greater than the light level to which the eyes have become adapted so as to produce disability or discomfort (Kaufman 1972; McCormick 1976). There are many types of glare, but three are perhaps most relevant to roadway and headlighting. These are blinding glare, disability glare, and discomfort glare (Allen 1970). Blinding glare can be defined as glare which is so intense than an object cannot be seen for an appreciable period of time (Kaufman 1972). Disability glare results in reduced visibility and visual performance, and is generally believed to be produced by stray light within the eye. It acts as if each source of glare produces a veiling light which reduces contrast and renders objects which are previously visible no longer visible. Disability glare is often associated with or accompanied by discomfort glare. Discomfort glare does not necessarily interfere with visual performance but produces discomfort, annoyance, irritation, or distraction (Allen 1970; Bennett 1977; Fry 1956; Guth 1963; Hopkinson and Collins 1970; Kaufman 1972; Schmidt-Clausen and Bindels 1974). It is believed that the mechanism of discomfort glare is different from that of disability glare. It has been proposed that it may be linked to the variation or activity in those muscles controlling pupil diameter (Fry and King 1977; Hopkinson and Collins 1970).

Olson (1978), in a recent review of headlighting and the comparison of European and U. S. headlighting systems, expresses clearly the main objective of headlamp designers. This is to provide a beam that maximizes illumination of the roadway while minimizing the glare for oncoming drivers. According to Olson, the "Catch 22" of headlighting is that the more powerful a headlamp is the more roadway illumination there will be, but at the same time there is more potential for producing glare for drivers of oncoming cars. Although glare is minimized when headlights are properly aimed, about 40% of the vehicles on the road have at least one misaimed headlamp. Olson rightly points out that not only is glare disabling, it is also discomforting, and the glare from headlamps increases the probability that the drivers facing headlamps from oncoming vehicles will not attempt to focus their eyes on those parts of the roadway which they should be monitoring.

Not only can misaimed low-beam headlamps cause glare but much more powerful high beams, when misaimed, have a greater potential for producing glare and can blind oncoming motorists. Hare and Hemion (1969) found that 82.25% of the vehicles they observed in their study of headlamp usage in the U. S. dimmed their high beams when meeting opposing vehicles. The mean intercar distance on dimming was 1,714 ft (522 m). Therefore, any glare would have to be produced by misaimed low beams. Bhise and his associates (Bhise et al. 1977) indicated, however, that properly aimed U. S. low beams could be assumed to be acceptable in terms of discomfort glare. The findings of Mortimer and Olson (1974) and Hull, Hemion, Cadena, and Dial (1971) support this conclusion in that the dimming request rate for current U. S. low beams is about 5%.

To summarize, it would appear that the use of properly aimed low beams at twilight and under conditions of reduced visibility should not produce unacceptable levels of glare for oncoming drivers. The use of headlamps at these times could, therefore, increase the ability of the driver to see and to be seen.

Age and Driving

It is well known that the aging process produces significant effects on the human senses. Corso (1968, 1971, 1975, 1977) and Botwinick (1973, 1978) as well as other writers (Birren 1964; Braun 1959; McFarland 1968; Weiss 1959; Fozard et al. 1977; Engen 1977; Kenshalo 1977) have reviewed a number of these changes. They have indicated that a wide variety of age-related changes occur in the visual system. Many of these changes relate to the driving task (Richards 1967, 1977). Some of these changes are a decrease in the amplitude of accommodation (or the process by which the eye changes focus for different distances) due to the hardening of the crystalline lens and perhaps changes in the muscular forces acting on the lens, a decline in visual acuity, a decrease in depth perception, and a reduction in pupil size and reactivity (the decrease of pupil size with age is called "senile miosis").

In addition, Blackwell and Blackwell (1971) have clearly shown that contrast sensitivity decreases as a function of age across a wide range of background luminances (0.001 to 500 fL [0.003 to 1710 cd/m^2]). According to the Blackwells, the greatest decreases in contrast sensitivity occur after the age of 45. People between the ages of 60 and 70 need about two and one-half times the contrast as those between the ages of 20 and 30 for good visibility. Similarly, Richards (1977) has shown that at age 40 about twice as much light is needed to see letters of low contrast, and by age 70 no Snellen letters subtending 2 minutes of arc at the eye (20/40 vision) were seen under the lowest light level employed (0.01 fL [0.03 cd/m^2]).

Closely related to driving performance are age-related changes in dark adaptation and glare sensitivity. In terms of dark adaptation (the increase in sensitivity with time in the dark), the threshold level reached by the older person is not nearly as low, in general, as that of the young adult (Birren and Shock 1950; McFarland and Fisher 1955; Domey, McFarland and Chadwick 1960). However, there is conflicting evidence as to whether or not it takes the older eye longer to reach a given level of dark adaptation (Birren and Shock 1950; Botwinick 1973, 1978; Corso 1975; Domey, et al. 1960; Fozard et al. 1977).

There is also a marked increase in the sensitivity of the eye to disability glare (Fisher and Christie 1965; Richards 1967; Wolf 1960) and discomfort glare (Bennett 1977) as well as a decrease in glare recovery (Burg 1967) with age. Wolf (1960) has investigated the relationship between the luminance necessary to be able to detect a gap in a Landolt-C (a type of acuity target consisting of a circle with a gap in it) target at different levels of glare. He found that the rise in sensitivity to glare was small up to about 40 years of age but increased rapidly between ages 40 to 70. It is believed that the increased opacity of the crystalline lens is the primary cause of the increasing sensitivity to glare. This results from the increase of scattered light in the lens and, to some extent, in the ocular media (Wolf 1960; Wolf and Gardiner 1965).

Schwab, Solomon, and Lyons (1972) investigated the monetary value drivers place on comfort as a function of age. Twenty-four drivers were required to choose between three headlight configurations with varying amounts of money subtracted from their pay. Subjects drove on a loop test track at night with controlled exposure to oncoming traffic. The headlight systems included the following: 1) a high-glare system employing conventional high beams; 2) a low-glare system employing conventional low beams; and 3) a low-glare system using high-intensity polarized beams. The results of the study showed that drivers over 47 were willing to pay more per hour for low-glare headlight systems than drivers under age 29. This indicates that older drivers are more sensitive to glare than young adult drivers.

Marmolin, Rendahl, and Sjukhuset (1977) examined the relationship between different aspects of mesopic night vision ability and age. Mesopic vision (Kaufman 1972) refers to "vision with luminance conditions between those of photopic and scotopic vision, that is, between about 1 fL (3.426 cd/m^2) and 0.01 fL (0.03 cd/m^2)". Mesopic vision ability was measured in terms of contrast sensitivity at two background luminances, contrast sensitivity during glare, glare recovery time, and night myopia (a continuous fluctuation in the state of accommodation of the eye where the focus is no more than 6 to 7 ft [1.8 to 2.1 m] away). In general, it was found that mesopic visual ability decreased with an increase in age. Mesopic visual ability presumably would be important to visibility under dusk/dawn conditions.

Box (1971) has indicated that drivers age 40 and over had 27% to 28% of the accidents examined in his study of urban freeway lighting. In the lighted section of the freeway 18% of the accidents and in the unlighted sections 29% of the accidents involved drivers in this age group.

In brief, many, although not all, older drivers would be under a more severe visual handicap when driving at night, during dusk or dawn, or under low ambient light levels than would a young adult driver. Of the operators' and chauffeurs' licenses issued in the state of Virginia from July 1, 1974, to June 30, 1978, 40.6% were to drivers age 40 and over. In addition, drivers age 45 and older accounted for almost 27% of the fatal accidents and 17% of all accidents resulting in personal injury during 1977. Therefore, the age of the driver is an important factor when considering changes in headlamp usage laws.

Other Factors for Consideration

Certain other factors relevant to headlamp usage also need to be briefly considered. First, changes in headlamp usage laws may have some influence on fuel consumption. Edman (1977) claimed that the energy consumed by headlights (low beam, 100 watts) is produced by relatively inefficient means, while fuel costs of energy supplied from the central stations is significantly less. From this he argued that 2 fc (22 lx) of fixed lighting in combination with vehicle parking lights would produce greater visibility and comfort for the motorist. Although it has been several years since Edman first presented these suggestions, it is unlikely that a significant difference in energy consumption will be obtained by having low-beam headlamps on 1 to 2 hours more per day in order to increase visibility during the dusk and dawn periods.

A second factor concerns the number of accidents on Virginia highways during the twilight hours and during periods of reduced visibility from weather conditions. Virginia Crash Facts (1977) indicate that there were 998 fatal accidents in Virginia during 1977. Of those accidents in which lighting conditions were specified, about 4.7% occurred during the periods of dawn and dusk. In addition, about 4.7% of all crashes occurred during the same twilight periods. It might be noted that the definition of the period of dawn and dusk is usually left to the discretion of the investigating officer. This does not provide a very precise definition of the prevailing light conditions as the amount of illumination changes very rapidly during this time.

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Weather conditions (e.g. fog, rain, and snow) can also reduce visibility and present a hazard apart from those concerned with slippery roads and skidding, etc. About 12.9% of the fatal auto accidents and 18.9% of all crashes (in which the weather conditions were specified) took place during periods in which visibility was limited by the weather. Therefore, a significant number of accidents took place in Virginia in 1977 during a period of reduced visibility (dusk/dawn and poor weather). It must be noted, however, that an accident is a complex event in which visibility may be only one factor.

With regard to weather conditions and visibility, it is well known that the atmosphere is never perfectly transparent and unless the viewing distance is very short, atmospheric losses will occur. This can reduce illumination at the eye and shorten the visual range. The maximum daylight visual range or distance at which a large dark object (about the size of an automobile) can be seen against a light background (i.e. the horizon sky) is presented in the <u>IES Lighting Handbook</u> (Kaufman 1972) for different classifications of fog and visibility. The visual or optical ranges (distances) are for a value of 5% contrast, which is usually considered representative of the daylight contrast threshold. Generally speaking, fog and cloud particles act to scatter light and reduce contrast of objects at a distance. For example, in what is considered an "exceptionally clear" atmosphere the visual range is 30+ miles (18.75 km), while in what is termed "thick fog" the visual range is reduced to about 660 ft (201 m). These values are derived from a particular case of Koschmieder's law in which

$$e = T^{V_o},$$

where e is the minimum perceptible contrast (0.05 or 5%), T is transmissivity (T per mile), and V_o is the visual or optical range (miles). See Table 1 for values of visual or optical range and transmissivity for various visibility descriptions. This relationship should be useful in determining when visibility is reduced enough to require the use of headlamps. In particular, the requirement that headlamps be turned on whenever visibility is limited to 500 ft (152 m) appears to be well within the visual range of 660 ft (201 m) for the "thick fog" category.

Table 1

Transmissivities and Meteorological Optical Ranges for Various Visibility Descriptions

Visibility Description	Meteorological Optical Range (Visual distance), V_o (miles and km)	Transmissivity (T per mile)
Exceptionally clear	30+ (18.75+ km)	greater than 0.90
Very clear	30 (18.75 km)	.90
Clear	10 (6.25 km)	.74
Light haze	5 (3.12 km)	.55
Haze	2 (1.25 km)	.22
Thin fog	1 (0.62 km)	.05
Light fog	½ (0.31 km)	.0025
Moderate fog	¼ (0.16 km)	$10^{-5.2}$
Thick fog	1/8 (0.08 km)	$10^{-10.4}$
Dense fog	1/16 (0.04 km)	$10^{-20.8}$
Very dense fog	100 ft (30.5 m)	10^{-69}
Exceptionally dense fog	50 ft (15.2 m)	10^{-137}

Source: Kaufman (1972)

ILLUMINANCE MEASUREMENTS

Illuminance levels were measured during the dusk/dawn period to determine if adequate ambient light was available for seeing. Illuminance measurements were made with a Gossen Panlux Electronic Luxmeter in an off-street suburban location in the Atlanta area. The Gossen Luxmeter was calibrated using a Gamma Scientific Model 200 Standard Lamp.

The results are presented in Tables 2 and 3 and in Figures 1-4. Due to a lack of direct sunlight on the cell unit of the meter, the maximum light levels obtained at visible sunrise and sunset and after sunrise and before sunset probably represent conservative estimates of ambient illumination. Those readings obtained after sunset or before sunrise should be neither underestimates or overestimates as no direct sunlight would have been available. Two readings were taken before, during, and after sunrise and two readings were taken before, during, and after sunset. The weather conditions ranged from partly cloudy and mostly clear to clear.

The investigations of Gallagher et al. (1974) and Fischer (1975) and the recommendations presented by Edman (1973), the CIE (1965), and IES (1977) suggest that the average roadway illuminance level necessary for adequate seeing is on the order of 2 fc (22 lx). However, the values of illuminance obtained by Box (1971), Allen and Carter (1964), and by this investigator at these times (see Tables 2 and 3 and Figures 1-4) indicate the ambient sky illumination level is about 0.06 fc (0.65 lx). Illuminance levels change rapidly during the dusk/dawn period and by visible sunrise and visible sunset the illuminance levels are well above the 2 fc (22 lx) level (again, as measured by Box, Allen and Carter, and this investigator). Therefore, headlamp usage between visible sunset and sunrise would seem to be indicated to allow the motorist to see and be seen.

Table 2

Illuminance Measurements Taken Before, During, and After Visible Sunrise

Date: 12/25/78 Weather: clear

Time (a.m.)	fc	lux	
7:10	0.10	1.076	
7:15	0.25	2.69	
7:20	0.73	7.86	
7:25	2.10	22.60	
7:30	5.60	60.26	
7:35	11.00	118.36	
7:40	19.50	209.82	Visible Sunrise
7:45	30.50	328.18	
7:50	48.00	516.48	
7:55	64.00	688.64	
8:00	82.00	882.32	
8:05	97.50	1049.10	

Date: 12/29/78 Weather: partly cloudy and mostly clear

Time (a.m.)	fc	lux	
7:10	0.09	0.968	
7:12	0.10	1.076	
7:15	0.20	2.15	
7:20	0.52	5.60	
7:25	1.51	16.25	
7:30	3.95	42.50	
7:35	8.00	86.08	
7:40	15.00	161.40	
7:42	18.50	199.06	Visible Sunrise
7:45	23.00	247.48	
7:50	34.50	371.22	
7:55	49.00	527.24	
8:00	57.90	623.00	
8:05	67.00	720.92	

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Table 3

Illuminance Measurements Taken Before, During, and After Visible Sunset

Date: 12/25/78 Weather: clear

Time (p.m.)	fc	lux	
5:15	69.00	742.44	
5:20	50.00	538.00	
5:25	36.00	387.36	
5:30	24.00	258.24	
5:35	14.70	158.17	Visible Sunset
5:40	7.90	85.00	
5:45	3.40	36.58	
5:50	1.30	13.99	
5:55	0.45	4.84	
6:00	0.15	1.61	
6:05	0.06	0.65	
6:10	0.03	0.32	

Date: 12/27/78 Weather: clear

Time (p.m.)	fc	lux
5:15	71.00	763.96
5:20	41.00	441.16
5:25	29.00	312.04
5:30	16.50	177.54
5:35	10.50	112.98
5:37	8.00	94.69
5:40	6.50	69.94
5:45	3.20	34.43
5:50	1.35	14.53
5:55	0.50	5.38
6:00	0.16	1.72
6:05	0.06	0.65
6:07	0.05	0.54
6:10	0.03	0.32

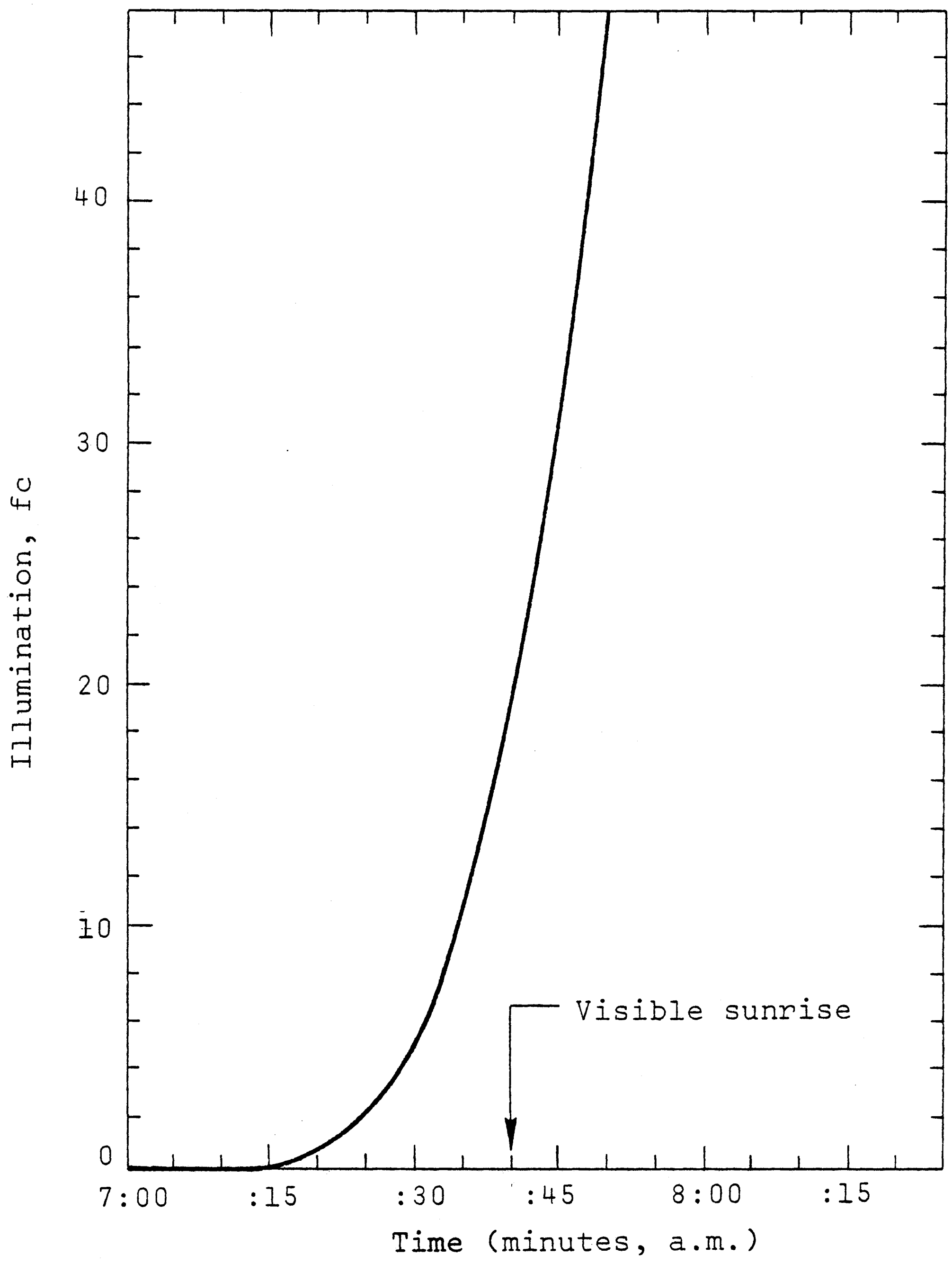

Figure 1. Illuminance measurements taken before, during, and after visible sunrise 12/25/78.

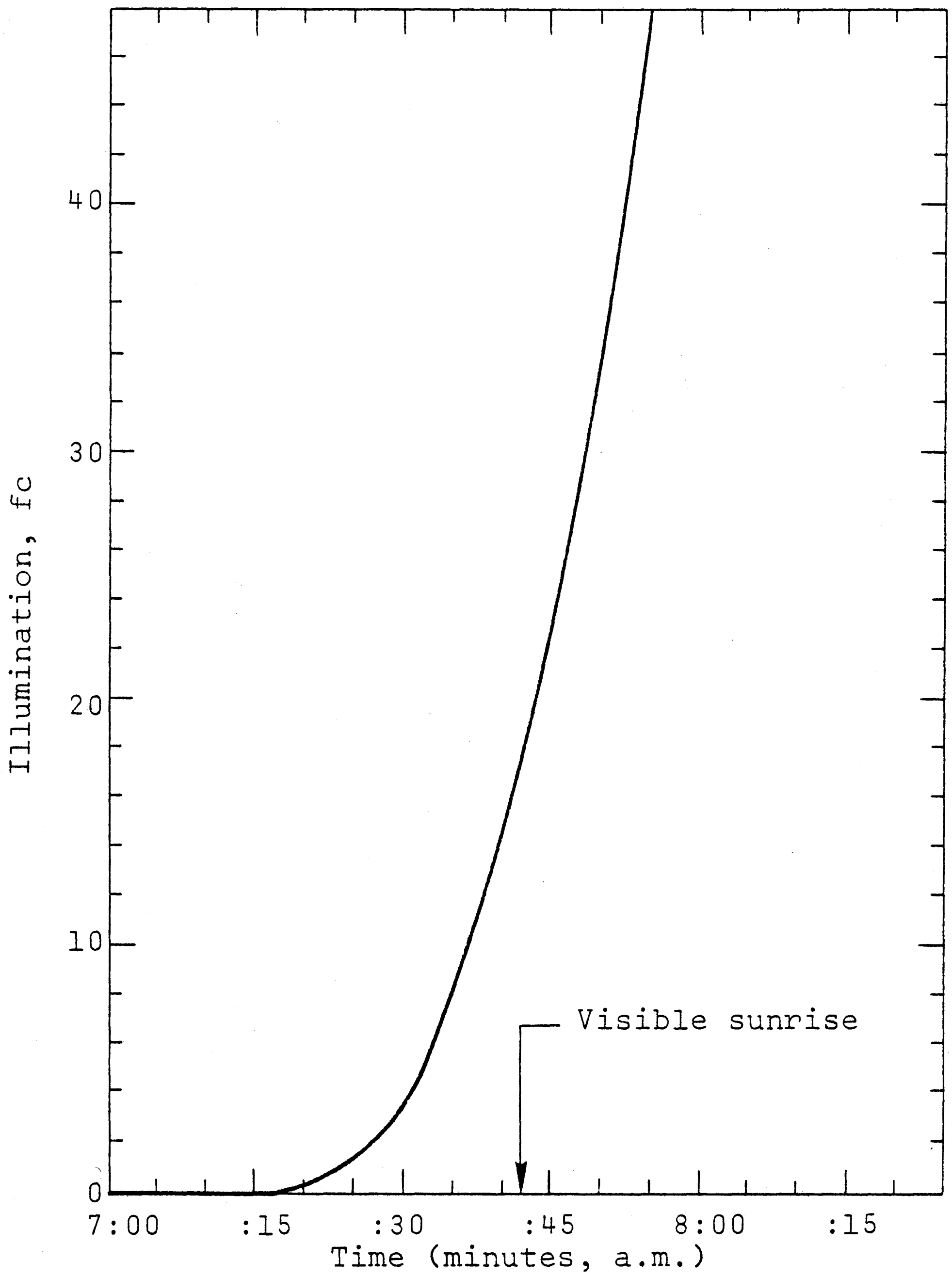

Figure 2. Illuminance measurements taken before, during, and after visible sunrise 12/29/78.

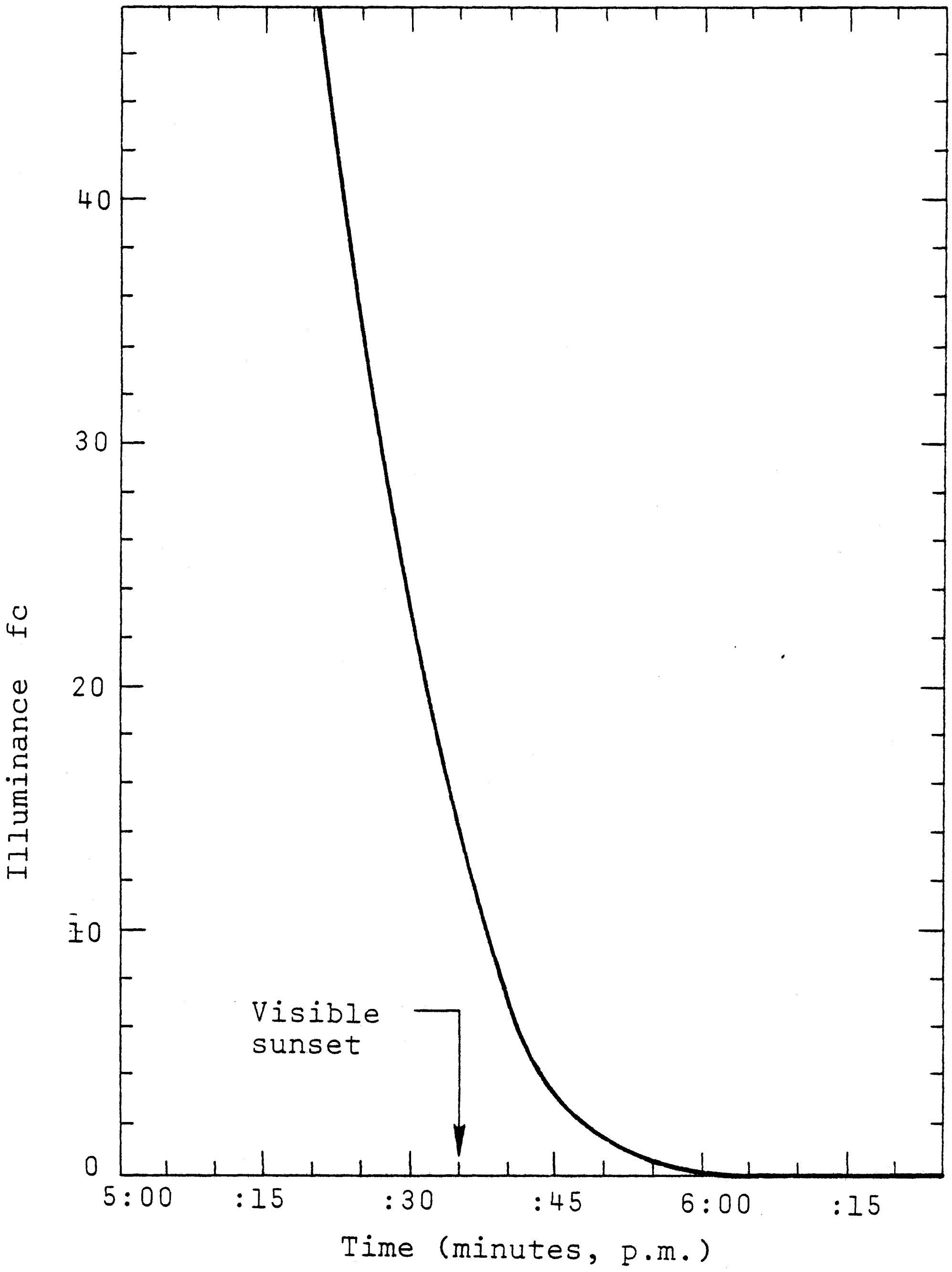

Figure 3. Illuminance measurements taken before, during, and after visible sunset 12/25/78.

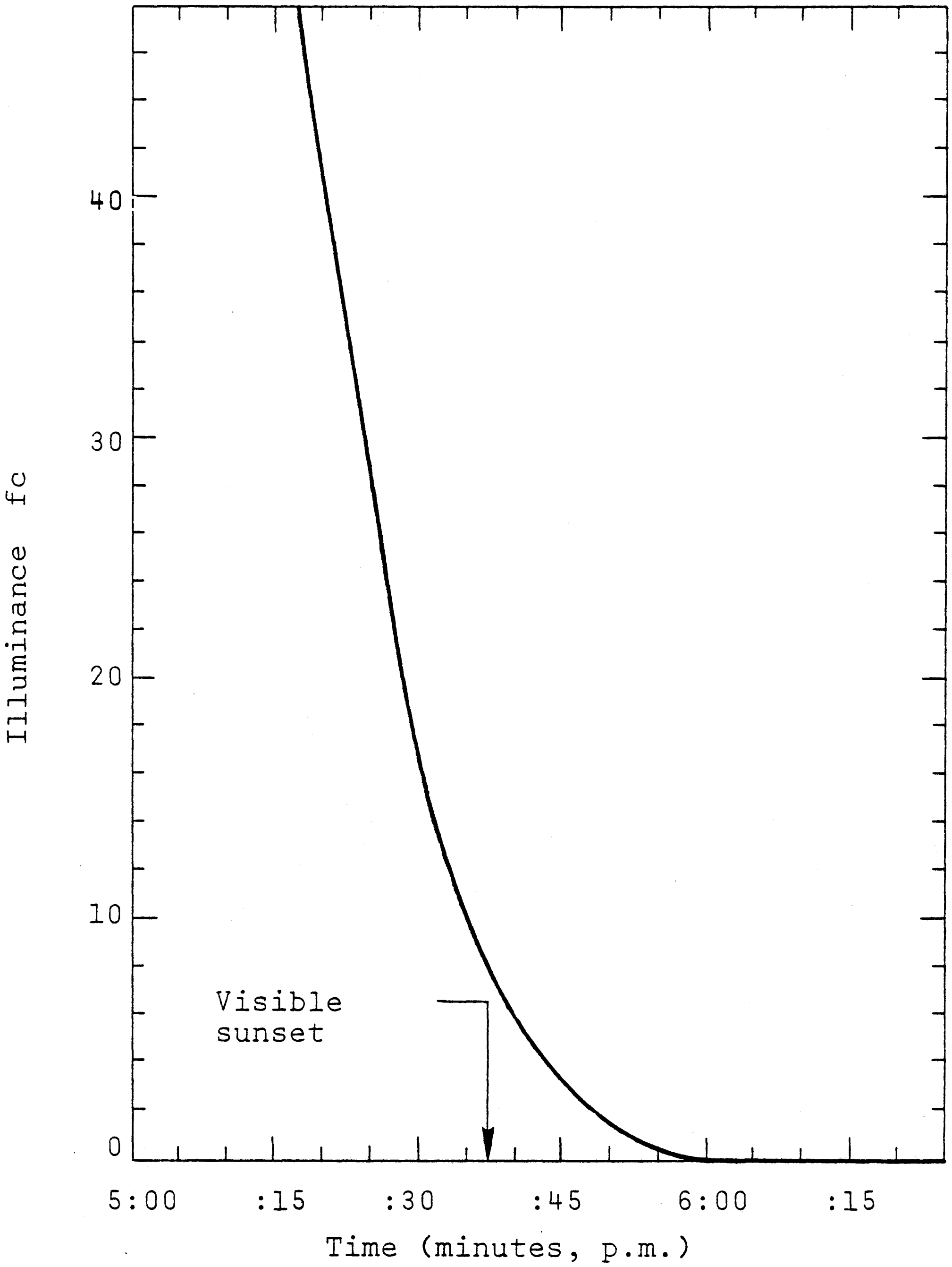

Figure 4. Illuminance measurements taken before, during, and after visible sunset 12/27/78.

SURVEY OF LAWS ON HEADLAMP USAGE AT DUSK, DAWN, AND TIMES OF LIMITED VISIBILITY

A survey of laws on headlamp usage at dusk, dawn, and times of limited visibility was conducted for the various states using the questionnaire shown in Table 4. The results of the survey are shown in Tables 5 and 6. Thirty-five of the states replied using the self-addressed and stamped envelope that was provided, while fourteen were contacted by telephone.

The most frequent, or modal, requirement regarding headlamp usage at dusk and dawn (involving about 66% of the states reporting) was to turn on headlamps 30 minutes after sunset and keep them on until 30 minutes before sunrise. It is entirely possible that this requirement might be based on the occurrence of Civil Twilight, which is about 20 to 40 minutes after visible sunset and before visible sunrise. It might also be noted that Box (1971) used Civil Twilight to determine the beginning and end of darkness or night in his study of freeway accidents and streetlighting. The results of the current survey are shown in Table 5.

The most frequent requirement regarding the use of headlamps under conditions of limited visibility (involving about 54% of the states reporting) was that headlamps be used whenever visibility was limited to 500 ft (152 m). The results of this aspect of the survey are shown in Table 6.

It would appear that the present headlamp usage laws of the state of Virginia are in line with those of the majority of the other forty-nine states. However, this does not mean that the headlamp usage laws of Virginia, as well as those of other states, do not need improvement or amending in order to be brought into line with modern driving conditions and requirements. Indeed, the laws of the other states which differ from those of Virginia might well be used as precedents for changing or modifying the Virginia laws.

Table 4

Questionnaire Used to Determine Headlamp Usage Laws at Dusk/Dawn and Under Conditions of Limited Visibility

This questionnaire is for the Virginia Highway and Transportation Research Council and involves the construction of a list of laws and requirements of various states in the U. S. relative to headlamp usage at sunrise and sunset and at times of poor visibility. Please fill out this questionnaire and return it in the stamped and addressed envelope which has been provided. Your cooperation in this effort will be greatly appreciated.

1. The name of your state is ______________________________.

2. When are automobile headlamps in your state required to be turned on? (Check the appropriate space)

   a. at sunset _____.

   b. before sunset _____. If before sunset indicate how long before __________.

   c. after sunset _____. If after sunset indicate how long after __________.

3. When are automobile headlamps in your state required to be turned off? (Check the appropriate space)

   a. at sunrise _____.

   b. before sunrise _____. If before sunrise indicate how long before __________.

   c. after sunrise _____. If after sunrise indicate how long after __________.

4. Is headlamp usage required when visibility is limited to a certain number of feet? Yes ___. No ___.

   a. If yes, indicate number of feet __________.

   b. If no, indicate determining factor (such as precipitation, fog, etc.) ______________________________________.

5. If your state does not have laws or requirements pertaining to one or more of the questions above (in particular 2, 3, or 4) circle the appropriate question number(s) below.

   2 3 4

6. Please feel free to list below any other headlamp usage laws in your state which you deem to be important.

Table 5

Categories of Headlamp Usage Laws at Dusk/Dawn in Various States of the U. S.

	Categories	Number of States Reporting
Category I:	No laws or requirements pertaining to headlamp usage at dusk/dawn.	1
Category II:	Headlamps on until 30 minutes after sunrise	2
Category III:	Headlamps on 30 minutes before sunset and until 30 minutes after sunrise.	3
Category IV:	Headlamps on at sunset and until sunrise.	11
Category V:	Headlamps on 30 minutes after sunset and until 30 minutes before sunrise.	33

Table 6

Headlamp Usage Under Conditions of Limited Visibility

Requirements	Number of States Reporting
No requirement indicated.	3
Requirement to turn on headlamps based on atmospheric conditions and not visibility distance.	2
Requirement to turn on headlamps when visibility limited to 609.6 m (200 ft).	5
Requirement to turn on headlamps when visibility limited to 1,524 m (500 ft).	27
Requirement to turn on headlamps when visibility limited to 3,048 m (1,000 ft).	13

CONCLUSIONS AND RECOMMENDATIONS

In the review of the literature those factors have been discussed which appear to be relevant to the visual requirements of motorists at dawn and dusk and during periods of limited visibility. These included the role of vision in highway safety and the relevant aspects of the visual environment at dawn and dusk, visibility and roadway lighting, conspicuity or vehicle noticeability, glare vs. headlighting, age, and other factors that might be concerned with headlamp usage.

The research of Gallagher et al. (1974) and Fischer (1975) and the recommendations of Edman (1973), the CIE (1965), and the IES (1977) suggest that the average roadway illuminance for adequate seeing should be on the order of 2 fc (22 lx). Considerably less illuminance than this exists one-half hour before sunrise and one-half hour after sunset. Values of illuminance obtained by Box (1971), Allen and Carter (1964), and by this investigator at these times indicate that the ambient sky illuminance is on the order of 0.06 fc (0.6 lx). Therefore, it is recommended that headlamps be turned on at the time of visible sunrise and sunset. There are four advantages to this recommendation: 1) illuminance levels at these times (even under overcast skys) are well above the 2 fc (22 lx) level (again, as measured by Box, Allen and Carter, and this investigator); 2) the use of low-beam headlamps increases the conspicuity, or noticeability, of a vehicle, and allows its placement on the highway with a minimum of glare (assuming properly aimed headlamps); 3) the older driver would be under less of a visual handicap; and 4) the enforcement of these headlamp requirements should be easier for the law enforcement officer and their obeyance easier for the driver than the existing requirements. In addition, there is precedent for this recommendation. The survey showed that 22% of the fifty states in the U. S. require headlamps to be on from sunset to sunrise.

The requirement that headlamps be turned on when visibility is limited to 500 ft (152 m) is a more complex problem. On the one hand, the visual range is 600 ft (201 m) for seeing a large dark object (such as an automobile) of 5% contrast against the horizon sky under visibility conditions described as "thick fog". If the motorist can see over 600 ft (183 m) even under these adverse weather conditions, then the present headlamp requirement is adequate. On the other hand, one argument for making a change in the law rests on stopping distances (AASHO 1967; Hare and Hemion 1969). At 55 mph the perception/reaction/stopping distance is 1,155 m (379 ft) on dry pavement, but it is 1,606 m (527 ft) on wet pavement. The value for stopping on wet pavement, therefore, exceeds the presently required visibility distance by 27 ft (8.2 m). An argument can, therefore, be made for turning on low-beam headlamps whenever there is any precipitation (e.g. rain, snow, or fog). In addition, this would ensure noticeability and proper placement of vehicles on the highway. This requirement would also be easily remembered and obeyed by motorists and enforced by legal authorities. The survey indicated that two states do not have a requirement to turn on headlamps based on visibility distance, but based on atmospheric conditions instead. Therefore, it is recommended that low-beam headlamps be used whenever there is inclement weather in addition to being used whenever visibility is not adequate for 1,524 m (500 ft). As a practical matter, headlamps should be turned on whenever the windshield wipers are turned on as is required by the state of Georgia. These recommendations should contribute to highway safety in the state of Virginia.

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