Advancement in Roadway Lighting

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● SIGNIFICANT ADVANCEMENT in roadway lighting depends on the combined action of many people, including the best engineering skills, scientific research personnel, and facilities.

One of the objectives of this paper is to arouse interest in the benefits which will be produced by attention to better seeing conditions for night driving. The scientific resources available, which should be directed toward the improvement of night seeing conditions, include the personnel of all federal and state highway departments, and some universities, institutes, associations, and committees.

Also, individual contributions based on thoughtful use of one's knowledge should be highly significant. To make progress, knowledgeable, shrewd people must speak up, tell what they know, and show how it can help improve the tremendous multibillion dollar industry or business of night motor vehicle transportation.

Many American people desire, or may be required, to drive the streets and highways after dark or before dawn. During the hours of darkness roadway lighting should be appropriately used to extend and continue the efficient and pleasant use of motor vehicle transportation facilities.

POSSIBLE PUBLIC BENEFITS

Serious consideration should be given to the public benefits of good night seeing conditions such as:

1. Night transportation should also operate efficiently.
2. Increase value of automotive-highway investment.
3. Better environment for social, recreational, business activities.
4. Development of useful land areas.
5. More pleasant, less fearsome night driving.
6. An improved standard of night living for night motorists.

Helping provide these benefits by means of good night seeing conditions is the humanitarian objective which has impelled the development and more widespread use of roadway lighting. The lighting of municipal streets, highway interchanges, and roadways extending through, around, beyond, and between sizeable centers of population and business activity is worthy of immediate attention.

Night Transportation Should Also Operate Efficiently

Efficient motor vehicle transportation requires reasonable night as well as day speeds. When roadway lighting is used to provide good seeing conditions, safe or critical speeds are higher than for dark streets or highways. The economic value of time saved with higher critical speeds justifies many roadway improvements, including roadway lighting for night traffic. The economic benefit is used in the justification of many roadway improvements. The saving may amount to more than the cost of roadway lighting. Roadway lighting should increase safe speeds by 10 to 20 mph.

When only 2,500 vehicles per night increase average speed from 45 to 60 mph, the economic value of time saved amounts to $6,000 per mile per year (Fig. 1). This is based on the outmoded $0.02 per vehicle minute estimate. When time is evaluated at the current rate of $0.06 per vehicle minute, the economic saving is increased to $18,000 per mile per year.

Critical, or safe, night driving speeds are higher and more nearly approach daytime speeds when lighting is provided for good seeing.

Utilize Highway Capacity During Darkness.—The after-dark, evening, or early morning capacity or efficiency of roadways depends on the seeing conditions provided. Operations such as avail of passing opportunities, headways, lane use, and merging

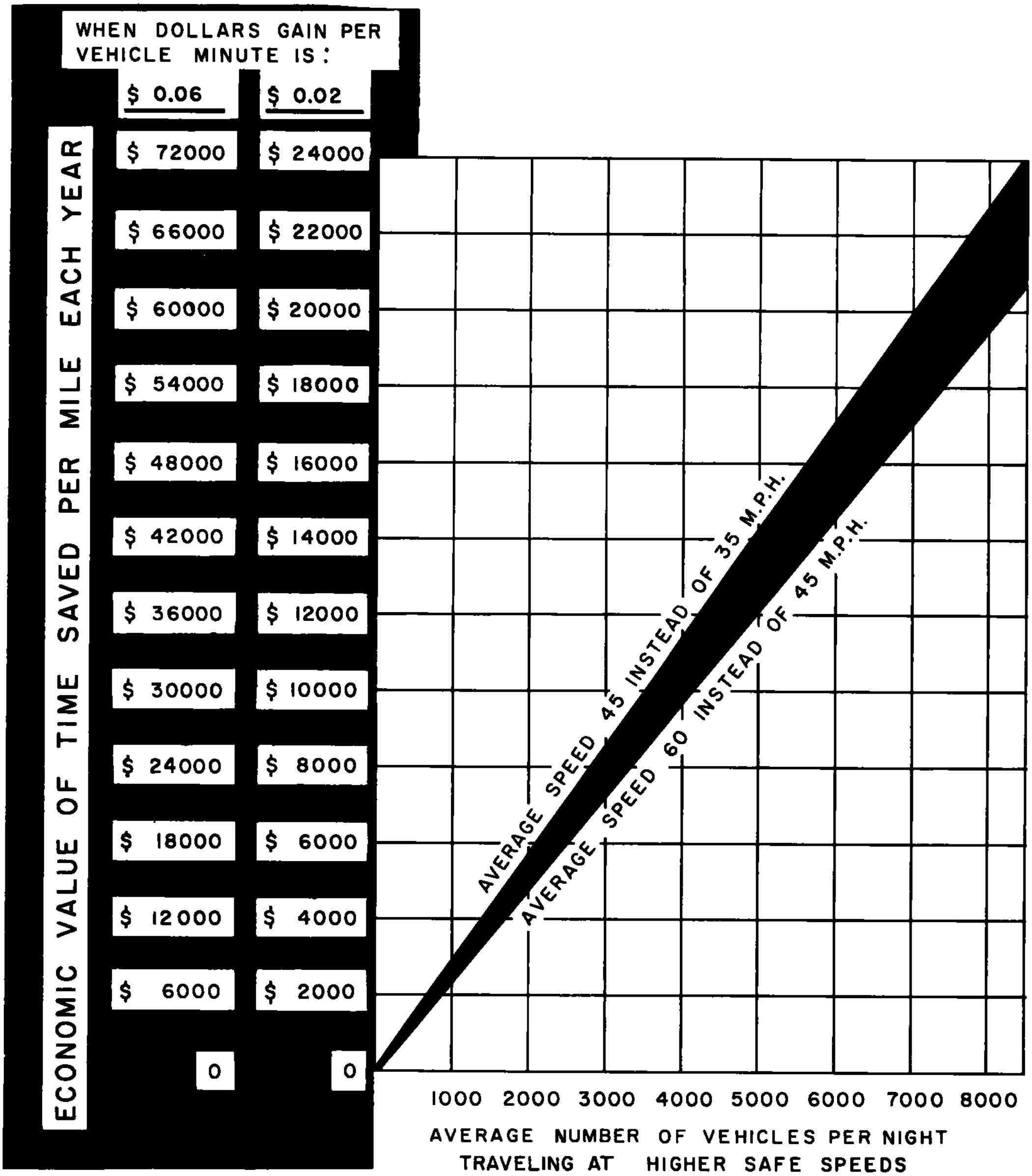

Figure 1. Economic value of time saved, due to higher critical or safe speeds, also applies to night traffic. Roadway lighting should increase safe speeds by 10 to 20 mph. When only 2,500 vehicles per night increase average speed from 45 to 60 mph, the economic value of time saved amounts to $6,000 per mile per year. When time is evaluated at $0.06 per vehicle minute, this economic saving is increased to $18,000 per mile per year.

of vehicles are improved by lighting for good seeing. The safe, expeditious movement of large numbers of vehicles requires quick and accurate seeing on which good driving judgment is based.

The U.S. Bureau of Public Roads, the Connecticut State Highway Department, and other interested agencies are seriously considering engineering studies of the improvement in heavy traffic conditions, such as capacity achieved by means of roadway lighting.

Increase Value of Automotive-Highway Investment

Better seeing conditions for night driving will continue, extend, and expand the benefits of motor vehicle transportation. Increasing the dividends received from a worldwide multibillion dollar investment—industry or business—may be considered vital to progress.

Pleasant, attractive night driving conditions encourage increased use of streets, highways, autos, trucks, and buses. Turnpike toll highways are being lighted to assist and attract night motorists. The lighting of interchanges is most prevalent.

The increase in financial dividends through motor fuel tax revenue may be reinvested in additional facilities for the public benefit. Figure 2 shows an example of the state and Federal motor fuel tax revenue that may be generated by night use of streets, or highways by various volumes of traffic. After-dark use may account for sizeable proportion of the over-all fuel tax receipts.

Those who use these facilities at night and provide this substantial revenue may believe that they should be appropriately aided by the improvement in seeing conditions which roadway lighting provides. Improvement of roadway and vehicle facilities usually attracts and encourages the people to make more use of such facilities.

The appropriate use of roadway lighting is a night use improvement which may produce an appreciable increase in motor fuel tax revenue. If the average increase in traffic volume is 3,000 vehicles per night, the increase in revenue to the state is more than $5,000 per mile per year. In addition, there may be an annual increase of $2,500 per mile for the Federal road program. The motor fuel tax receipts shown in Figure 2 are based on the assumption that the average vehicle consumes one gallon of gasoline for each 15 miles of travel. The $0.07 per gallon state tax and the $0.035 per gallon Federal tax are representative.

Better Environment for Social, Recreational, Business Activities

It has been estimated that a large percentage of the over-all travel-use of streets and highways in the United States is generated by social and recreational motives. Family contacts during the evening hours may be considered highly important.

Tourists may be an attractive business enterprise as well as an activity which brings pride of one's community. It is generally reasonable to assume that the people do not desire that all such activities be confined to the daylight hours.

Some countries are purposefully floodlighting buildings, foliage, monuments, and installing lighted fountains to obtain beautiful effects for the benefit of tourists as well as the local populace. Obviously the roadway paths to be traveled to and from such centers of attraction should be adequately lighted.

Often people enroute to a destination may prefer to drive at night rather than delay, or instead of having less time the next day for sight-seeing or business activity.

Night street or highway travel may be a matter of necessity in getting to, or from, centers of employment or shopping. Peak traffic conditions may occur during the hours of darkness or near-darkness, particularly during the short daylight hours of winter. Road capacity and traffic efficiency may be most important at night. It has been estimated that 90 percent of the people in the U.S. travel by automobile. Trucks, buses, and air or rail terminals now also operate on a 24-hr basis for the delivery of people and goods. Night shift employees and after-dark customers deserve serious consideration. Lighting is good business.

Shopping centers and other roadside business establishments remain open after dark. They enhance their own private business at night by providing lighting on their property for the comfort, convenience, and protection of their customers.

The wide extent of this privately financed lighting activity should be an indication of the public desire and approval of appropriate lighting on the streets and highways which provide access to after-dark business establishments. These customers should not be rushed away for a hurried return home in order to avoid driving or walking along dark streets or highways.

Continuation and extension of prosperity during the hours of darkness is a normal, logical public desire. Many activities which aid the general over-all economy of an

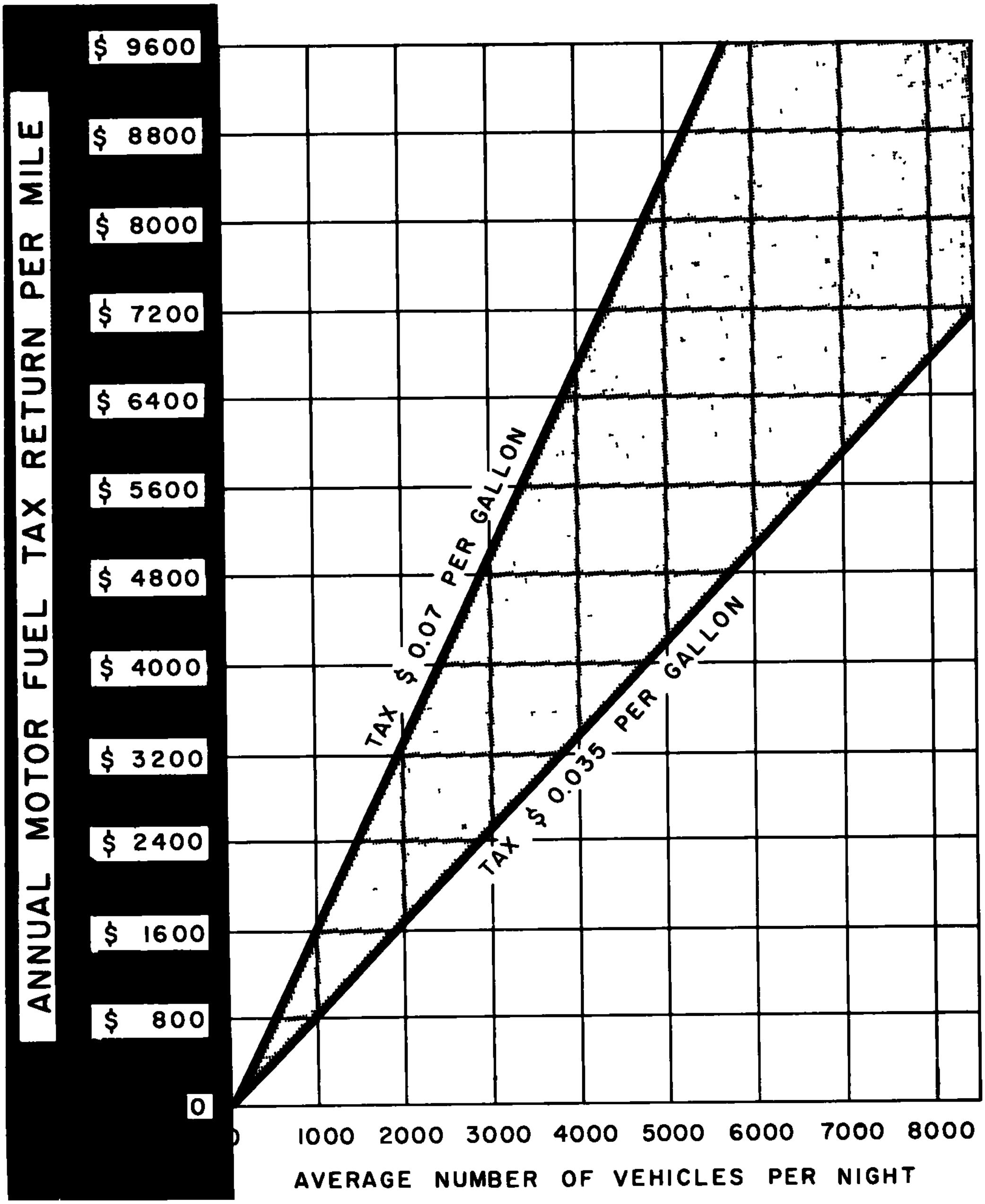

Figure 2. Night use of motor-vehicle transportation facilities generates a sizeable proportion of state and Federal motor fuel tax receipts. Increased night use with the encouragement which good seeing provides should produce an appreciable increase in fuel tax revenue for over-all, day-as-well-as-night, improvement of the roadway system. When the volume (or the increase) of night traffic averages only 3,000 vehicles per night, the annual state revenue is more than $5,000 per mile. In addition, there is $2,500 for the Federal road program, including a small percentage for research. The motor fuel tax receipts are based on consumption of 15 miles per gallon of gas, and $0.07 and $0.035, state and Federal tax, respectively.

area may be kept open—and made even more prosperous—during the hours of darkness by using the highly efficient lighting aids that are now available.

Development of Useful Land Areas

After-dark access to an area with comfort, convenience, and safety is an obvious requisite for area (property) desirability and development. This benefit results from almost all highway improvements. Roadway lighting appropriately used should favorably affect property values. Night living in a community is more pleasant and secure when lighting is provided.

More Pleasant, Less Fearsome Night Driving

"Drive at night" is a reasonable suggestion when good seeing conditions are provided to produce a pleasant, attractive, convenient motorist experience. Roadway lighting helps provide an environment free from fear.

The "don't-drive-at-night-if-you-can-avoid-it" attitude may apply to motorists who are fatigued or otherwise handicapped; but even when partially incapacitated people do persist in driving after dark, good seeing conditions assist them.

Good seeing is also essential for the protection and assurance of the other motorists or pedestrians who also happen to be on the road at night—the "other fellow" who may be shielded by another vehicle must be seen to be avoided.

The traffic safety benefits of good night seeing conditions are generally appreciated. Roadway lighting for good seeing helps the driver discern an impending traffic situation soon enough and at a distance in advance which is sufficient to avoid collision.

Being able to see the vehicle path ahead, the roadway, its alignment, and objects thereon often make the difference between a safe versus hazardous condition.

Removing the "cloak of darkness" by means of lighting is an effective aid to control of night criminal activities.

This is well known by the police. There are many instances in which robbery, vandalism, etc. have been appreciably decreased by adding the protection of lighting.

And the journey-trouble-stops (such as a flat tire) along a highway at night are less fearsome to contemplate when lighting has been provided to aid repairs or law enforcement.

An Improved Standard of Night Living for Night Motorists

Roadway lighting helps raise the standards of night living for night motorists, pedestrians, and others who do not desire to confine their activities to the daylight hours. Insurance costs should be lowered by the general use of lighting.

The economic gains and dividends to be attained by means of lighting may be large and worthy of very serious evaluation and consideration. A progressive attitude toward night activities may favorably influence the value of property. The value depends on usefulness when the people have the time and the desire to utilize. Increasing the value received from the public automotive-highway investment may produce a tremendous over-all improvement in the national or local economy.

For example, an automobile would be of little or no value if it must stay in a garage. Such facilities are of more value if they can be used—at night as well as during the day—with comfort, convenience and safety (Fig. 2).

Other Benefits

There are also other motivations, opportunities, and obligations which should place use of adequate roadway lighting and evaluation of its benefits uppermost in the minds of engineers and scientists, as well as all others who represent the American public, night business activities, and night motor vehicle transportation.

Good roadway lighting is an obvious indication of community progress and desire to prosper. Such an improvement of night living conditions should be seriously considered by all those responsible and accountable for the public welfare.

STUDY IMPROVEMENT IN NIGHT TRAFFIC CONDITIONS

The sizeable potential increase in night use and the value of streets, interchanges, and highways extending through, around, beyond, and between sizeable centers of population and business is worthy of immediate attention.

Roadway lighting advancement is notable because of the number of installations being made, the extent and amount of light being provided, also because of the adherence to the technology by which the essential good seeing conditions are achieved at nominal cost. Obviously this involves the engineering approach.

The night transportation industry, business, and prosperity, can be benefited by evaluating the economic improvement produced by adequate seeing. Figure 3 is an over-simplification of the objective factors. Evaluation and appraisal of the benefits, including comfort, convenience, facilitation, efficiency, accident prevention, and freedom from fear, is essential. The roadway lighting considered should be effective in

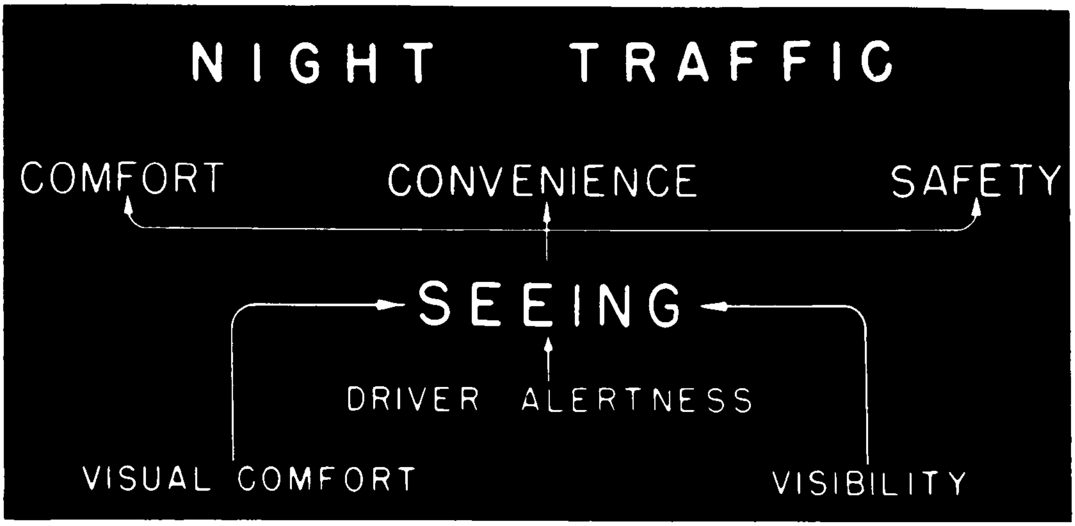

Figure 3. Public or operational traffic benefits derived from pleasant and efficient night use of the multibillion-dollar investment in automotive transportation facilities requires good seeing conditions. Effectiveness of roadway lighting is improving the seeing factors and visual comfort; visibility may now be rated so as to provide a basis for evaluation and ratings for the resultant increase in night traffic benefit.

producing visual comfort, visibility, and proper driver aspect.

Night traffic studies include the following:

1. Highway safety study.
2. Connecticut Turnpike study.
3. Texas intersection studies.
4. Michigan State driver efficiency studies.
5. Studies encouraged by I.T.E. Committee on Roadway Lighting.

Highway Safety Study

One of the recent significant traffic and seeing developments has been the publication of a report of the Highway Safety Study conducted under the direction of Charles W. Prisk, U.S. Bureau of Public Roads.

This report stresses the need for better and more general understanding of the fundamentals in:

> ...transportation, driver research,...perception,...judgment,...decision making,...fatigue,...loss of vigilance,...skill fatigue,...

etc. Considering all advantages to driver and other social advantages, it can be concluded that modern street lighting adequately designed and operated, does improve safety in most city situations ...the driver becomes 100 percent involved since obviously no action takes place on the highway except at his instigation...there is less critical knowledge about him...the ways in which the demands of the task are adapted to the characteristics of the human being will be a determinant of the safety and efficiency with which the highway-transportation system will function...the highway itself is the one permanent structure of highway safety, working 24 hours a day every day in every year to fulfill its public service function....

...Comfort, convenience, and safety are considerations of importance equal to a consideration of capacity, in today's highway planning. This concept of adequate facilities requires modern techniques for handling traffic...The Bureau of Public Roads has initiated appropriate cooperative studies with State authorities so that sorely needed new concepts, criteria, and techniques will be developed for determining the true value of continuous lighting on rural highways.

Additional pertinent excerpts from this report are presented for ready reference in Appendix C.

Connecticut Turnpike

Congratulations are due the U.S. Bureau of Public Roads for their research studies of roadway lighting, such as those conducted on the Connecticut Turnpike (2, 45). Traffic volumes were low during the studies which have been made. It is hoped that studies and analysis will be continued on this highway and the 17-mi extension into the City of New York which will soon be lighted continuously.

Texas Intersection Studies

The U.S. Bureau of Public Roads is also cooperating with the Texas Transportation Institute and the Texas Highway Department in studies (2) of intersection illumination.

Michigan State Driver Efficiency Studies

T.W. Forbes' paper on "Some Factors Affecting Driver Efficiency at Night" is given elsewhere in this Bulletin.

Institute of Traffic Engineers Committee on Roadway Lighting

The foregoing is also in line with the Resolutions Favoring Research on Roadway Lighting which was Adopted by Institute of Traffic Engineers Committee on Roadway Lighting, Detroit, Michigan, September 23, 1957. "The I.T.E. Committee on Roadway Lighting strongly endorses additional research on the benefits of roadway lighting, including driver comfort, traffic safety, roadway capacity, and other factors."

USE ILLUMINATING ENGINEERING AID

Some of the aids available for the improvement of night motor vehicle transportation have been developed by illuminating engineering, its industry, and initiative. Recent advancement will be discussed under the following headings:

1. Products which are more efficient and effective in producing good seeing.
2. Improved roadway lighting practice essential for efficient night transportation.
3. Ratings for evaluation of the visual seeing effectiveness of roadway lighting systems.
4. Instrumentation recently developed for field measurement of seeing factors.

More Efficient Products

The efficiency with which lamps and luminaires produce seeing has been appreciably increased during the past year, further enhancing a long-range upward trend. In announcing new products in June 1959, the General Electric Outdoor Lighting Department's General Manager stated "a luminaire sells for 20 percent less per lumen of output than in 1939—the cost of other things the utility buys have gone up—coal up 130 percent since 1939; copper up 200 percent; steel up 165 percent; but street lighting luminaires are down 20 percent. Here is what has happened to what cities buy: roadways up 250 percent; public buildings up 175 percent; motor vehicles up 150 percent; street lighting luminaires down 20 percent."

Installation, maintenance, and power costs are reduced by new mercury lamps which not only produce more than 50 lumens of light per watt, but also operate 9,000 hr, more than 2 years, with only 12 percent reduction in light output. A few years ago the few lamps that lasted that long had as much as 50 percent loss of light when operated 2 years. This is a 4:1 improvement in light output at the end-of-two-year lamp life. Replacing lamps once every 2 or 2½ yr obviously involves much less labor than was required for filament lamps which were replaced two or three times each year. This is as important for remote intersections as for systems of several hundred or several thousand luminaires.

The trend in roadway lighting (predicted 10 years ago) is back to arc lamps now in the form of mercury arc discharge lamps.

The use of 1,000-watt mercury lamps, producing more than 50,000 lumens in each luminaire, is rapidly increasing along with a general appreciation of the visibility really essential for night driving.

A contribution by the luminaire manufacturers is a completely new look in luminaires involving large tooling investments to lower the costs of installing and maintaining luminaires in the field. The manufacturer now mounts and wires the components inside a sleek, modern die cast housing. The utility or contractor is not now required to mount, and wire, or maintain each component separately. The integrated luminaire comprises:

1. Lamp, reflector, refractor for light direction and control.
2. The ballast-reactor for efficient operation of the mercury lamp.
3. A photoelectric control to automatically turn on the lamp at night when needed, and turn it off in the morning when the light from the lamp is not needed.
4. A single terminal board to which incoming power wires are attached.

New acrylic plastic refractors are now available for some luminaires. This is one answer to glassware breakage, wherever it is a problem.

Another interesting product development has recently been installed on Manahawkin Bridge by the New Jersey State Highway Department. The cost of low mounting height lighting from the bridge rail will apparently be cut in half by using modern production tooling. Some bridge designers do not like poles. Maintenance is easy. Individual units may be used as obstruction markers. The Manahawkin installation is said to be the first actual installation of lighting permanently designed into a bridge railing. The New Jersey State Highway Department has for many years invested in the maintenance and operation of roadway lighting involving many thousands of luminaires.

Sight Production

Due to advances in luminaire developments and proper use of available data, the visibility effectiveness of modern roadway lighting systems continues to increase appreciably and is now much higher than that obtained from roadway lighting as of 20 years ago.

The visibility and visual comfort effectiveness of luminaires is being improved by increased attention to the factors shown in the lower portion of Figure 5 (1, 2, 3, 4, 5, 6, 7, 12, 13). For example:

1. Control, or cutoff, of luminaire candlepower at driver approach distances from the luminaire greater than the top of auto windshield cutoff (shown shaded in Fig. 4) improves visual comfort and visibility:

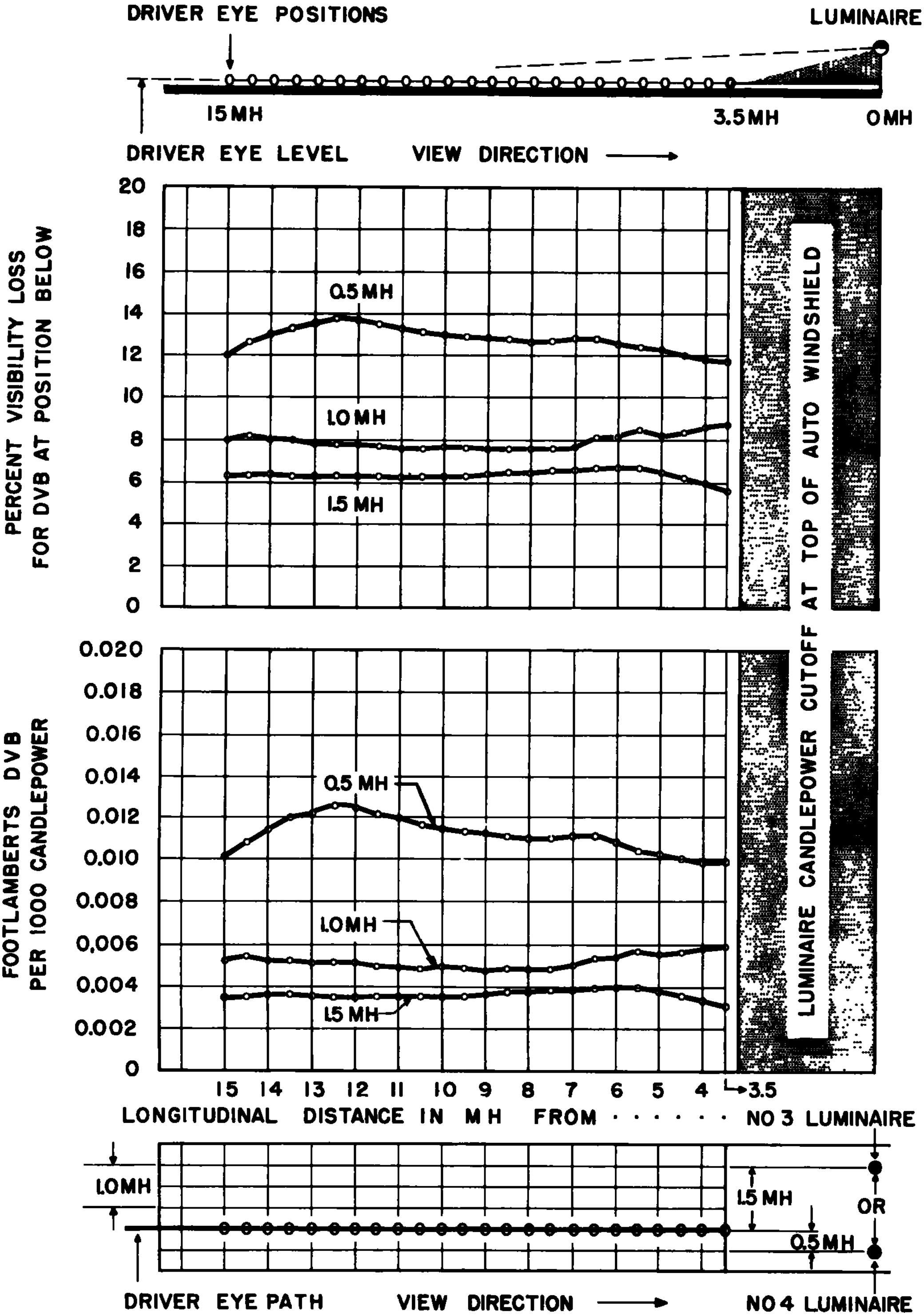

Figure 4. The visibility significance of cutoff, or sharp diminution of candlepower from a single roadway lighting luminaire, at distances greater than top-of-auto-windshield-cutoff, is shown by this data diagram for several representative driver paths along roadway. Luminaire candlepower extending out to longitudinal distances such as 15 MH, or 450 ft from luminaire produces about the same loss of visibility due to DVB as equivalent candlepower extending only 3.5 MH, or 105 ft from luminaire.

a. Visual comfort is improved by decreasing the actual luminaire brightness and the range of fluctuation shown at the left of Figure 5.

b. Visibility is improved by decreasing the percent loss due to DVB (disability veiling brightness) as shown at the right side of Figure 5.

2. Appropriate build-up and proportioning of the candlepower distribution at distances from the luminaire less than the top of auto windshield cutoff (shown unshaded in Fig. 6) increases visibility without detracting from the gains described under "More Efficient Products."

a. The relative effectiveness of candlepower in producing pavement brightness along the roadway (Fig. 6) shows that for reasonable uniformity of pavement brightness, the candlepower should be increased, with increase in longitudinal

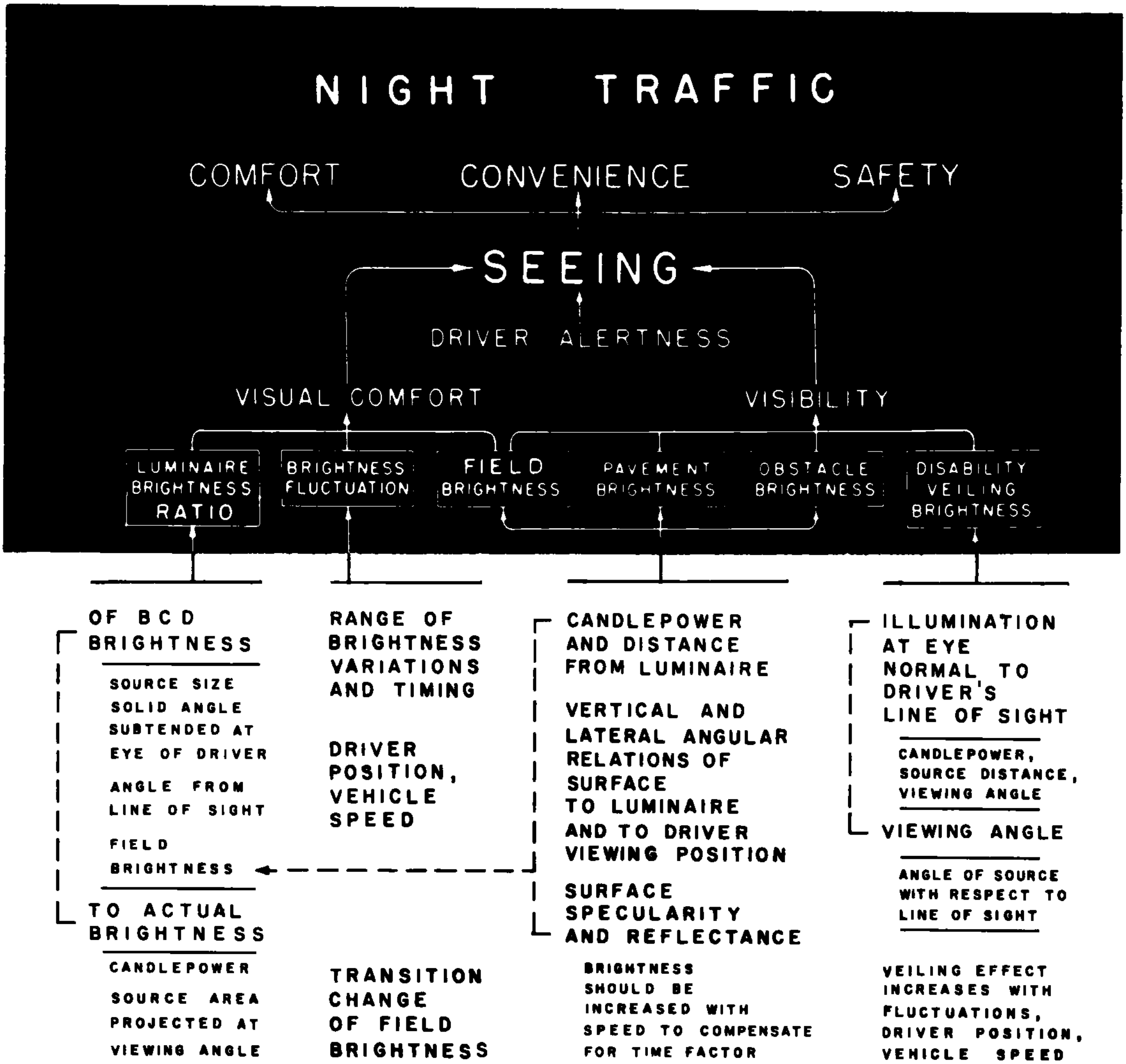

Figure 5. Data, emphasis, control, and balance of roadway lighting factors shown in lower portion, produce the visual comfort and visibility factors in seeing. Intermediate factors such as luminaire brightness ratio, fluctuation, field brightness, pavement brightness, obstacle brightness, and the percent visibility loss due to disability veiling brightness may also be rated and correlated to provide effectiveness ratings in terms of relative visual comfort and relative visibility. This simplification may be presented in terms of the two minimum ratings shown in Figure 3. Night public-traffic benefit is usually contingent on the seeing factor effectiveness of the roadway lighting provided.

distance extending out from the luminaire to distances of 3 to 3.5 MH.

b. Appropriate proportioning of candlepower distribution improves:
   (1) Pavement brightness for visibility by silhouette contrast.
   (2) Obstacle brightness for visibility by reverse silhouette or direct discernment.
   (3) Field brightness for visual comfort. Field brightness is the average integrated brightness in the driver's field of view, including that of the pavement, and objects thereon and nearby.

By comparison of Figure 4 with Figure 6, it is apparent that the cutoff of luminaire candlepower distribution coordinated with the top of auto windshield cutoff with respect to the driver's eyes, for average motorists and representative motor vehicles is highly desirable. This is one of the performance features of modern luminaire development, design, and manufacture.

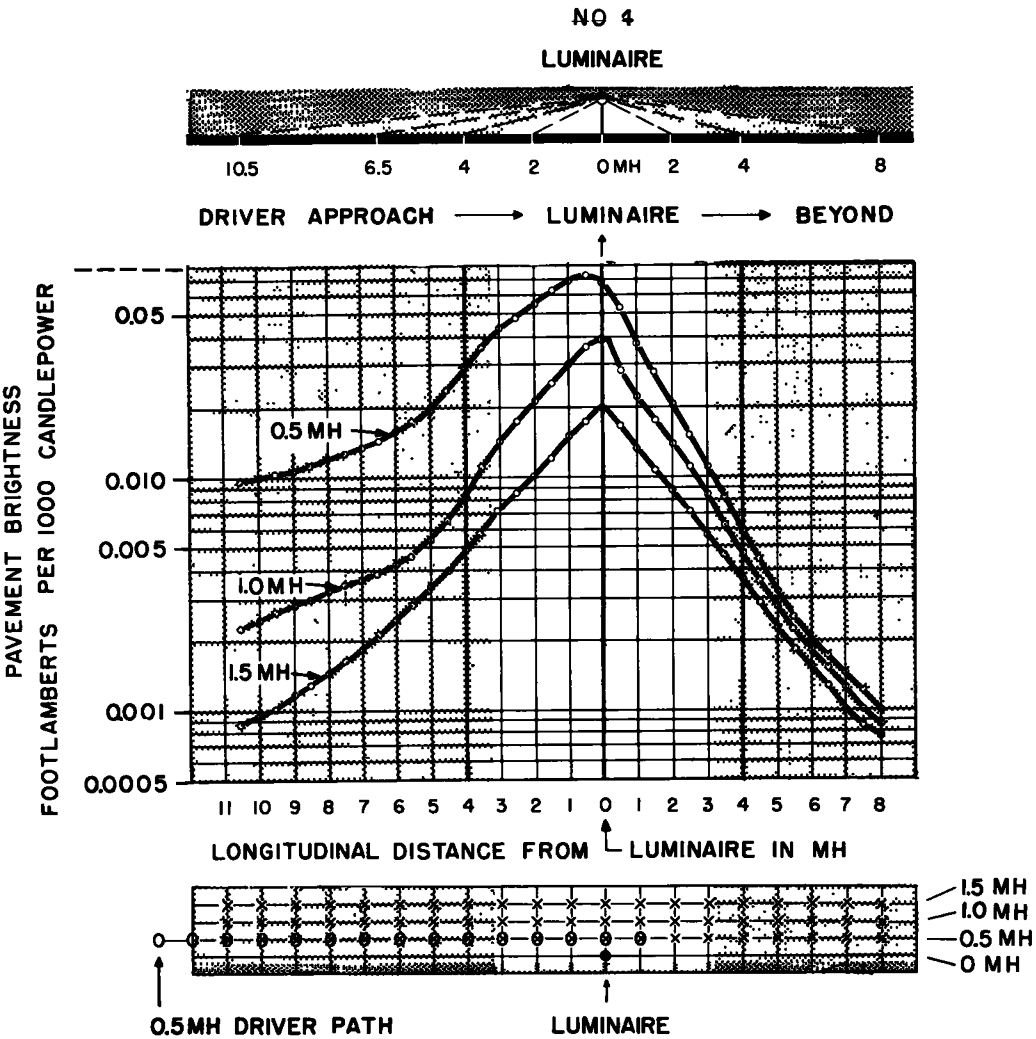

Figure 6. The highly significant pavement brightness factor in roadway lighting visibility is built up by increasing candlepower from luminaire with longitudinal distance up to that of top-of-auto-windshield-cutoff, which is shown shaded in this data diagram. The lower portion indicates driver-observer path, also transverse dimensions with respect to luminaire for representative longitudinal roadway lines along the pavement.

There are exceptions, such as luminaires for residential lighting, where long spacings between luminaires for economy and moderate driving speeds often justify extending the luminaire candlepower cutoff to longitudinal distances beyond 4.5 MH from the luminaire.

Additional information on the features of effective luminaire candlepower distributions and roadway lighting systems is readily available in other papers.

Improved Roadway Lighting Practice

There has been recent world-wide improvement of roadway lighting practice for using luminaires advantageously. The night traffic and seeing objectives, shown in Figure 3, form the broad basis for roadway lighting systems which produce pleasant attractive night driving conditions and generate even greater public enthusiasm. There has been increased effort to use the most effective manner. Also now much more information is available (1, 2, 3, 4, 5, 6, 9, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26).

An engineer's recommendations for the layout of a roadway lighting system have been based on his knowledge, experience, and desire to achieve at least a certain minimum in visibility and visual comfort. He has these seeing objectives in mind which will benefit and are of interest to the motorist. Now, fewer mental interpolations and compromises are necessary.

The lighting installation must serve the fundamental purpose of public benefit—evaluated in public benefit terms of visibility and visual comfort. Improvements in practice have been:

1. Use of seeing factor visual criteria.
2. Provision of transition lighting.
3. Better system geometry.
4. Recipe-type recommended layouts.
5. Clarification of A.S.A. practice.
6. Adequate vs less-than-adequate.

Use of Seeing Factor Visual Criteria.—With public benefit in mind, one of several statements in the 1953 A.S.A. Practice for Street and Highway Lighting (9) can now be implemented. For example:

> Proper distribution of the light from luminaires is one of the essential factors in efficient roadway lighting. The light emanating from the luminaires is directionally controlled and proportioned in accordance with the requirements for seeing and visibility described in Appendix A.

Seeing and visibility data is now more readily available in useful form. The engineer, desiring certain visual comfort and visibility results, based on actual or assumed conditions now considers the following:

1. Luminaire candlepower data along the roadway, tabulated, or plotted, in terms of the driver's eye-level paths, or longitudinal lines along the pavement.
2. Data constants or factors (such as those shown in Fig. 4 and Fig. 6) which when multiplied by luminaire candlepower and/or combined for the proposed roadway lighting system, indicate effectiveness in terms of seeing factors (such as those shown in Fig. 5 and Fig. 7).
3. The characteristics of the system including any desirable variables in visibility criteria such as, pavement, or object, surface reflection of light to provide brightness, luminaire candlepower cutoff; and variables in visual comfort criteria such as, size of luminaires and field brightness.

The methods of presenting and using the requisite data and computing the effectiveness of roadway lighting systems have been outlined in a series of technical papers published by I.T.E., I.E.S., the Highway Research Board, and summarized during 1959 (1-7).

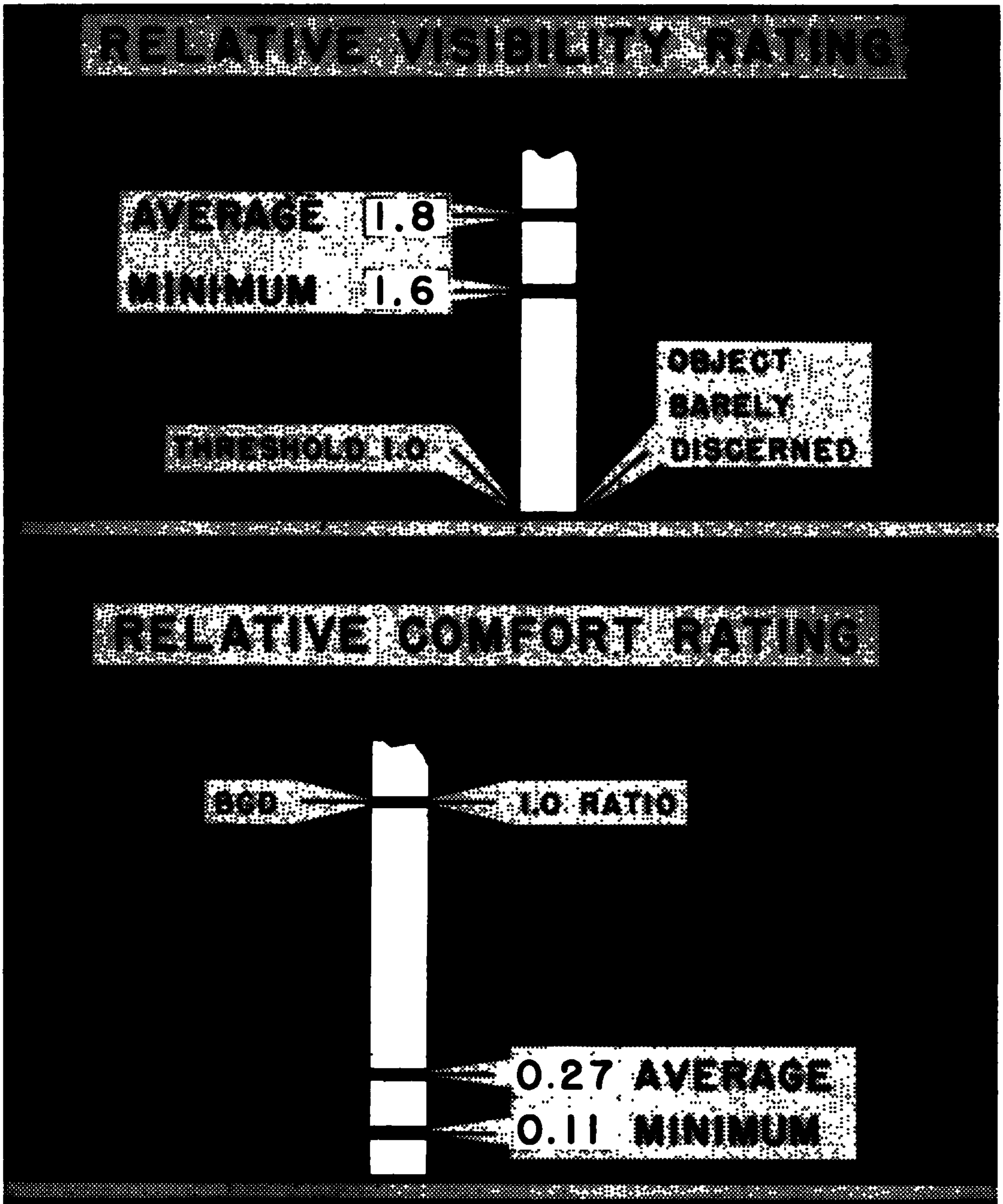

Figure 7. Example of seeing factor ratings for a representative roadway lighting system which provide simplification for the motorist, public officials, and engineers. The minimum ratings are most significant. Visual comfort ratings are relative to the motorist sensation which would be at BCD, the average borderline between comfort and discomfort, for the system of luminaires and the lighted roadway. Visibility ratings are relative to 1.0 threshold, bare discernment, in accordance with the scale of the Low-Range Luckiesh-Moss Visibility Meter

At least one consulting engineering firm (28) is computing visual effectiveness ratings for a client's proposed roadway lighting system. The purpose is to select the most beneficial type of luminaire source combination.

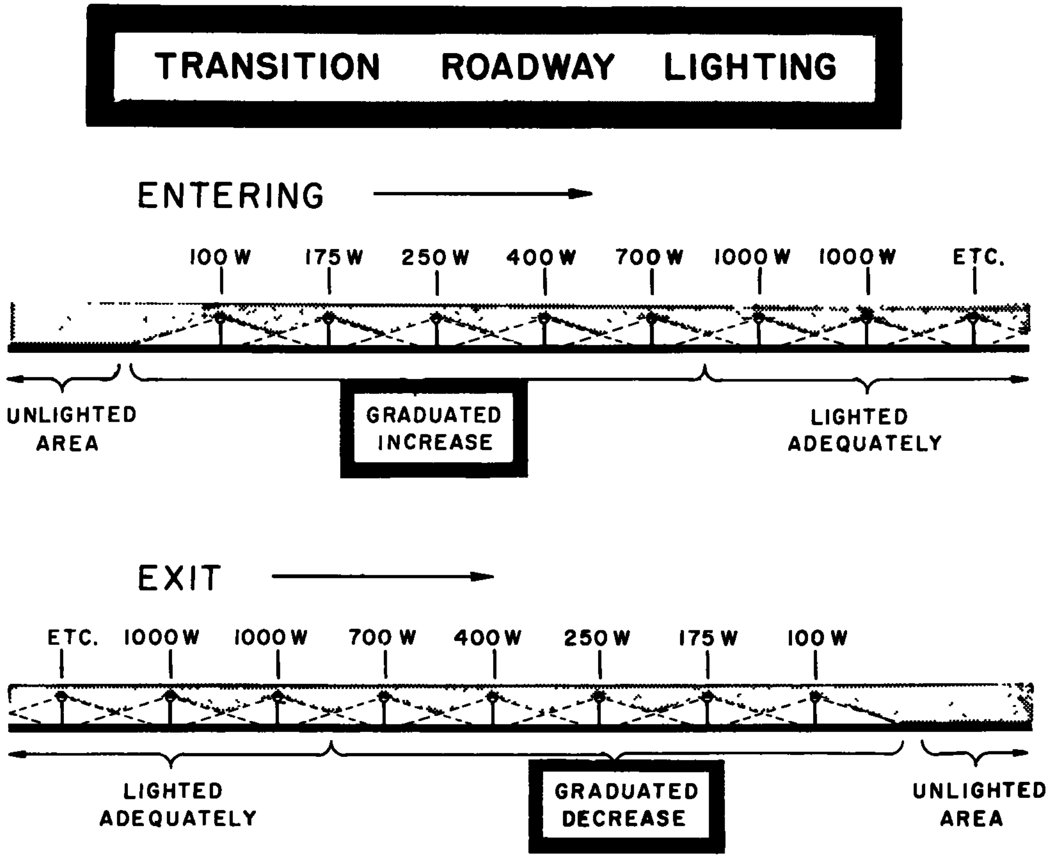

Figure 8. For more pleasant motorist sensation when approaching, entering, or emerging from an adequately lighted system, the lighting may be extended in each approach and exit direction. By using approximately the same spacing and size of luminaire and graduating the size of lamp, the brightness in the driver's field of view is tapered upward or downward for entrance of exit, respectively. The ranges of watt variation shown are now available in mercury lamps.

Provision of Transition Lighting.—The driver sensation when approaching, entering, or emerging from an adequately lighted section of roadway is being carefully considered to make this transition pleasant. Prevailing driving speeds tend to make this change of brightness in the motorist's field of view somewhat abrupt. Gradual build-up and tapering-down the brightness in the driver's field of view may be highly desirable. This may be accomplished by extending the lighting system in each approach and exit direction, approximately the same spacing and size of luminaire, but graduating the size of lamp used.

For example (Fig. 8), if 1,000-watt mercury lamps are being used for the lighted section of roadway, the entering or emerging brightness may be gradually modified by extending the lighted roadway installation to include 5 additional luminaires in each direction. On the approach side of the lighting system, the size of lamps is successively increased. The first luminaire may have 100-watt mercury lamp, the second 175 watt, next 250, then 400, 700, followed up by the 1,000-watt lamp providing the seeing required on the principal or primary portion of the lighting installation. For emerging traffic the lighting is extended with the size of lamps successively reduced from 1,000 watt to 700, 400, 250, 175, and 100 watt in sequence (Fig. 8).

Now the aforementioned flexibility in size of mercury lamps is available; also, the relamping of the different sizes of lamps is now an occasion which occurs infrequently. The replacement time intervals may be longer than two years. Special attention to transition lighting is definitely preferable to providing less than adequate visibility over the principal portion of an entire roadway lighting installation, merely for the purpose of obtaining transition conditions which might be considered to be more pleasant for the motorist.

As the result of studies extending over several years, the Connecticut State Highway Department (29) has adopted recommendations calling for "a lower intensity of illumination in advance of and beyond each complete section of illumination... required to provide for the initial adaptation or accommodation of the eye from darkness to light and from light to darkness. It is generally considered that ten seconds for initial eye adaptation is adequate." Connecticut prescribed 1,000-ft lengths in each direction for rural areas, and 900- and 750-ft lengths for residential and commercial areas, respectively. In addition, "Areas on the main line (state highways) between illuminated

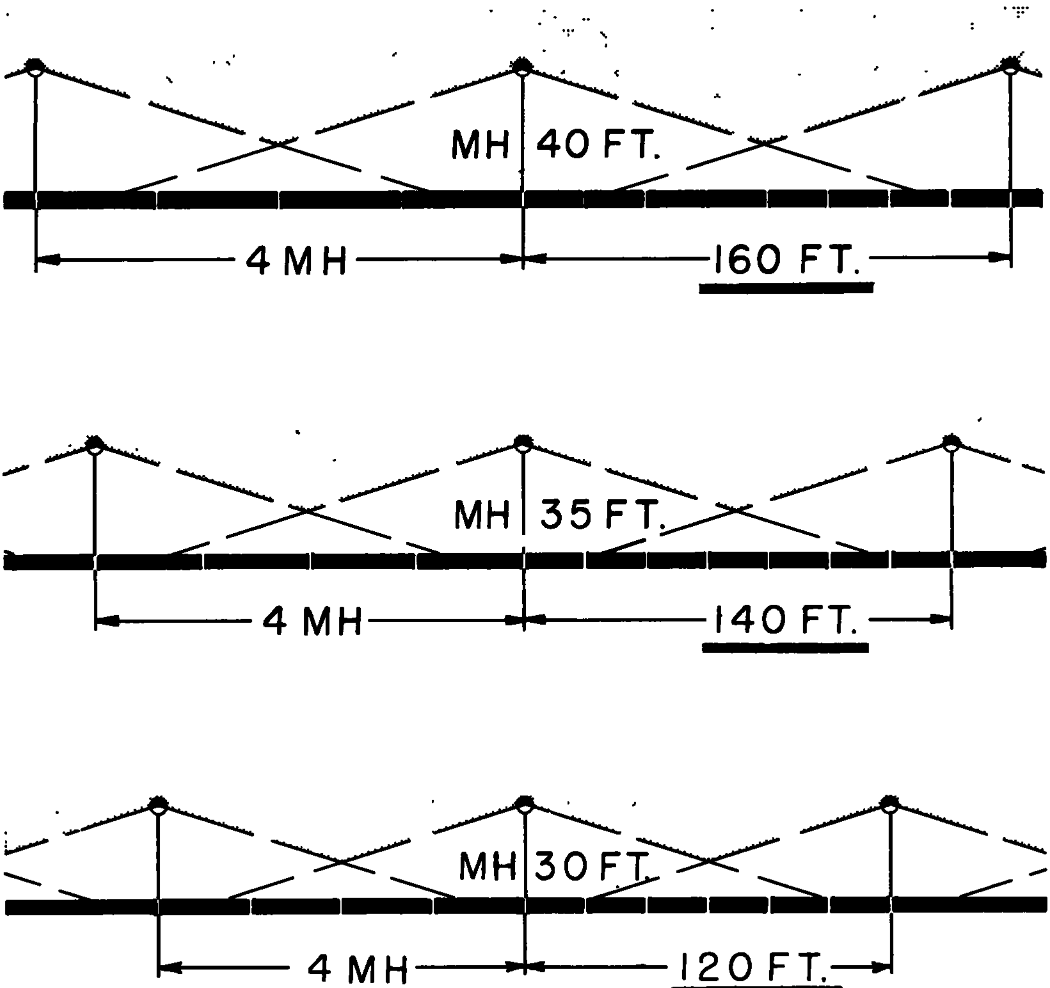

Figure 9. The trend toward higher mounting heights increases the longitudinal spacing distance between luminaires yet maintains the spacing ratio essential for good visual comfort and visibility. There are numerous 35-ft mounting height installations in the United States. Continental European roadway lighting practice includes an increasing number of installations with luminaire mounting heights of 40 ft or higher.

sections may be lighted if such darkness gaps fall within 60 seconds of travel time."

Better System Geometry.—There have been significant improvements in the geometry of roadway lighting systems, particularly with respect to luminaire mounting height, also including the longitudinal and transverse spacing between luminaires and overhang with respect to the edge of the traffic-used pavement. There are numerous installations where the luminaire mounting height is 35 ft, and the trend toward higher mounting heights is increasing rapidly.

One of many advantages of higher mounting is that the principles for good seeing shown in Figure 4 and Figure 6 may be adhered to with an increase in the longitudinal spacing distance between luminaires. For example (Fig. 9), 4 MH luminaire spacing is obviously changed in distance from 120 ft to 140 ft with a change of MH from 30 to 35 ft. Similarly 40-ft MH means an increase to spacing of 160 ft. This means fewer poles per mile of lighted roadway. Larger lamps with good control of the transverse width of candlepower distribution are often desirable to accompany higher mounting heights.

European roadway lighting practice continues to include an increasing number of installations with luminaire mounting height at 40 ft or higher (23, 24, 26, 30).

Recipe-Type Recommended Layouts.—Luminaire manufacturers, individually and as an industry group, now provide recommended layouts for roadway lighting systems in general. Some manufacturers also supply "recipes" for representative combinations of roadway conditions based on the use of a specific type of luminaire and lamp combination. Assumptions are made, which should be stated, regarding dirt accumulation on the luminaire, as well as the depreciation in lamp light output by the time of lamp replacement.

In providing such "recipes," the manufacturer gives serious consideration to the public benefit which will be assured at any time in terms of the seeing factors, visibility, and visual comfort.

Demonstrations of full-scale roadway lighting installations (16) now provide seeing aids for those who desire to visually appraise the effectiveness of "recipes" in providing comfort and visibility. Added value is obtained from such demonstrations when appraisal is implemented by means of standardized targets to be seen quickly, with certainty, and the observers are supplied with meters to measure and rate the relative seeing effectiveness provided by different systems. In Europe (23) this implementation-of-seeing-demonstration-technique has met with outstanding approval and resulted in the adoption of more advantageous lighting for night use of their roadways.

Clarification of A.S.A. Practice.—The 1953 American Standard Practice for Street and Highway Lighting can be misinterpreted as establishing objective goals which are only to be met or equaled. Instead, the real purpose of this publication was to present data regarding minimums, or not-less-than, base requirements which were a representation of practice in the United States current as of 1952, or seven years ago. Such recommendations are to be exceeded to the extent warranted and practicable. In the meantime, interest in encouraging pleasant night motor vehicle transportation has produced considerable progress in general understanding and use of information and data on the motorist and methods for rating and providing the requisite seeing. This paper and the References attached are an indication of progress since 1953. The following excerpts regarding American Standard should be understood:

> An American Standard implies a consensus of those substantially concerned with its scope and provisions...An American Standard is intended as a guide to aid the manufacturer, the consumer, and the general public...American Standards are subject to periodic review. They are reaffirmed or revised to meet changing economic conditions and technological progress.

During July 1959 the Illuminating Engineering Society published (I.E., p. 451) a Resolution of Intent, adopted by its Committee on Roadway Lighting and prepared by a Subcommittee on Interpretation of the American Standard Practice. This Resolution includes the following:

1. "Considerable confusion exists in the interpretation..."

2. "Proper consideration of luminaire and lamp depreciation during operation." The joint opinion of the Chairman of the Roadway Lighting Committee and the Chairman of the Subcommittee on Interpretation is that the foregoing means "when the illuminating source is at its lowest output in service and when the luminaire is in its dirtiest condition."

3. "That the illumination value recommended for limited access highways be expanded to consider such highways in urban areas as heavily traveled streets with no pedestrian traffic and that interchanges on such highways in such areas be treated in as near the same manner as surface street intersections in the matter of illumination."

According to the joint opinion of the Chairman of the Roadway Lighting Committee and the Chairman of the Subcommittee on Interpretation, this means that "in urban areas the average illumination on lighted limited access highways should be:

a. Between interchanges, 0.8 footcandle. This corresponds to the Heavy Vehicular traffic classification in Table 1 and Table 4 when pedestrian traffic is Light or None.

b. On interchange roadways, at least equal to the sum of the illumination values recommended for the two best lighted roadways approaching or entering the interchange."

Adequate vs Less-Than-Adequate.—The seeing effectiveness of roadway lighting systems may vary over a wide range. How much visibility and how much visual comfort may be considered as adequate depends on the public benefit desired, expected, or essential in terms of night motor vehicle transportation.

Evaluation of traffic benefit and other significant objectives will help determine:

1. The comparative importance of the seeing factors, visual comfort, and visibility.

2. The rating which each major seeing factor must have in order that adequacy may be assumed with reasonable assurance.

Current studies here and abroad will help firm-up estimates and recommendations. Continental European design and installation practice is establishing visual comfort as highly essential.

Unless roadway lighting is installed, its visibility benefit is not available. Visual comfort benefit helps get the lighting installed; helps make night driving pleasant and attractive so that the installation is backed by motorist approval and enthusiasm.

In order that public or traffic benefit be appraised and correlated with the visual effectiveness of the roadway lighting on which the evaluation is based, relative ratings are essential for the seeing factors such as visibility and visual comfort. If the roadway lighting has visual ratings which are inadequate, the traffic benefit produced can be expected to be less than the traffic benefit produced by lighting having good visual ratings.

The ratings for quality and quantity of seeing prescribed for new roadway lighting installations should include an estimated allowance, or safety factor, for the expected human capability of typical night drivers. Safety factors are customary in the layout and design of roadways. Seeing is a basic requirement for driving at night as well as during daylight hours.

It is also obviously a good practice to install roadway lighting which provides visual effectiveness ratings on the plus side of adequacy rather than borderline, or less-than-adequate.

On June 19, 1959, it was suggested to the I.E.S. Committee on Roadway Lighting that objectives be studied and that serious consideration be given to presentation of recommendations in terms of:

1. Minimum relative visibility and relative visual comfort ratings.

2. Pavement brightness, one of the principal factors in visibility, under roadway lighting conditions.

3. The minimum at any sizeable traffic-used position on the roadway as well as the minimum at any time, maintained in service.

4. Footcandles.

Minimum Relative Visibility and Relative Visual Comfort Ratings. For public night use of heavy traffic, high-speed highways were somewhat higher than those shown in Figure 7.

Pavement Brightness. A minimum of 0.6 footlambert was suggested. Appendix A and Appendix B show that the 0.6 number happens to be in line with the pavement brightness numbers recommended by the Netherlands (23, 31) and Great Britain (24). Neither of these two countries recommend footcandles. The Netherlands allow a 3:1 "ratio of the average brightness to any minimum in the road picture."

The use of pavement brightness criteria (instead of footcandles) is a definite, significant forward step toward visibility ratings. Generally the conventional types of candlepower distributions and roadway lighting systems which are effective in producing pavement brightness are also efficient in producing obstacle brightness, depending on object reflectance.

A glance at the left and right sides of Figure 5 shows that other control criteria are also essential for visibility and visual comfort. The Netherlands do recommend cutoff of the luminaire candlepower distributions.

The Suggestion for Minimum at Any Sizeable Traffic-Used Position on the Roadway. For the purpose of simplification, a single rating number instead of dual is used. Using the latter, a "minimum recommended average" is prescribed and then this number is supplemented with another ratio number stating that at some positions on the roadway the brightness (or footcandles) may be 1/10, or 1/4, or 1/3 the average. The actual minimum at any position is seldom known.

The seeing task should be seen at any position on the roadway. Discernment usually involves contrasts such as that of an object compared with the brightness of a sizeable adjacent pavement area. The areas can be expressed in visual solid angle at the driver-observer's eyes, or vertical and lateral angles or dimensions.

When certain visibility or visual comfort or brightness is essential, the roadway lighting system should provide it. If in accomplishment of the requisite a surplus is provided at other driver or object locations that should be all to the good, subject only to the efficiency economy requirements of the system. The minimum rating at any position is the most significant and logical criterion.

Footcandles. It should be thoroughly understood that comparison of two roadway lighting systems on the basis of footcandles is limited to instances when other circumstances are identical with respect to: (a) luminaire candlepower distribution extending along the roadway; (b) system geometry including luminaire spacing, mounting height, and overhang; and (c) pavement surface characteristics in reflecting incident light.

In his discussion of a paper published in May 1959, R. E. Ballard, engineer for the Connecticut Light and Power Company, recently phrased his opinion of footcandles very succinctly: "The use of footcandles as a measure of quality of illumination has long been recognized as a ridiculously outmoded crutch. Roadway lighting is intended to produce comfortable optimum visibility and there is not necessarily any relationship between footcandles and visibility as such."

Now that ratings for roadway lighting systems can be readily provided in terms of relative visibility and relative visual comfort, the engineer can transmit to others the seeing effectiveness which he has in mind, and avoid the confusion and complex mental interpolations with respect to benefit derived when footcandle data is used.

Ratings for Evaluation of the Visual Seeing Effectiveness of Roadway Lighting Systems

Seeing factor ratings for the effectiveness of roadway lighting, essential as a basis for progress in the evaluation of public benefit or traffic benefit, are being used here and abroad. To report topically:

1. Visual comfort, visibility, and factor ratings.
2. New requisite visibility-brightness studies by H. R. Blackwell.
3. Additional comprehensive evaluations are desirable.

Visual Comfort, Visibility, and Factor Ratings.—Ratings in use may be commented on as follows:

1. Computed rating method and data available.
2. Outdoor laboratory evaluation of visual comfort.
3. European ratings and studies.

Computed Rating Method and Data Available. Reported in (2) and (4). Provides a method of rating roadway lighting systems in terms of the seeing factors shown in Figure 5. For an example, combination of system conditions, the representative relative visibility, and relative visual comfort ratings are as shown in Figure 7.

The ratings for other existing or proposed roadway lighting systems may be readily computed. In addition to minimum (or overage if desired), relative visual comfort and relative visibility ratings for other factors may be computed; such as, pavement brightness (4), obstacle brightness, disability veiling brightness (DVB) with resultant visibility loss, luminaire brightness, etc.

Conversion constants (15), curves (4), and even nomographs (2, 4) are available for use with photometric luminaire candlepower data along representative longitudinal roadway lines (driver paths, etc.) (5, 6, 7). The extent by which specific rather than generally representative installation conditions are assumed depends on the precision required. Interpolative estimates based on ratings for other similar roadway lighting systems will evolve from use of seeing factor ratings.

Computation has many advantages including:

a. Predetermination or ratings for the effectiveness of proposed or existing roadway lighting systems is provided in readily understandable terms of roadway user benefit.

b. Installation practice luminaire performance variables may be explored, evaluated, and controlled in design for optimum over-all efficiency.

c. Comprehension of objectives will be improved, complexity reduced, and standardization possibilities revealed.

d. An ascending numerical scale is provided for visual comfort whereby improvement is accompanied by a higher number.

e. Progress in dynamic visual research under night driving conditions will be encouraged by a method for the use of laboratory and field data now available and that which will be made available in the future.

f. Time will be conserved. Computation facilitates ratings without the delays, uncertainties, and interference that may arise in field testing. The use of high-speed computer techniques is obviously feasible and desirable. With example ratings available, other ratings may be estimated by interpolative judgment.

The possible effect of new instrumentation in providing a larger scale range of numbers for relative visibility will be discussed under "Blackwell's Studies."

Technical paper presentation of the foregoing ratings and methods resulted in encouraging comments, such as:

> Joseph Barnett, Deputy Assistant Commissioner for Engineering, U. S. Bureau of Public Roads (June 12, 1959): Based on what you already have accomplished toward the evaluation of highway lighting in the form of relative visibility and visual comfort ratings, I am sure that in the future you will be able to make further improvements toward the rating of seeing effectiveness.

> T. W. Forbes, Assistant Director for Research, Highway Traffic Safety Center, Michigan State University: This paper is of much interest and importance in that it shows how factor ratings may be derived not only for the various factors in relative visibility but also for the comfort factors relating to glare. Veiling brightness has been widely recognized as of great importance because of its interference with visibility. The factor of discomfort has also been measured, but perhaps has not been thought of quite as much importance.

From the human factor and safety points of view, the comfort factor may be of as much importance as visibility. Reduced visibility from veiling glare, from spotty pavement brightness and all the other factors which have been so carefully analyzed are of primary importance, but visual factors leading to fatigue are also of major importance in the seeing task. Drowsiness may be induced by factors causing visual fatigue, or if present from previous lack of sleep, discomfort glare may enhance drowsiness and result in complete eye closure (32). The paper...suggests a method by which these various factors may be put together, including this highly important comfort factor, to produce a relative rating for roadway lighting...

But whether or not other and better methods of deriving such a rating are developed, the importance of such an undertaking seems very evident...demonstrating a procedure by which this may be done, thus laying the groundwork for further development.

Also it may be that with the increasing availability of electronic computers further developments along the line suggested will furnish a set of badly needed data for the mathematical simulation both of vehicle operation and separately of traffic flow under night driving conditions. Such simulation is being developed and when achieved will represent a scientific breakthrough which will facilitate highway and safety research of all sorts. For accurate simulation of night driving conditions as well as for valid rating of roadway lighting, combination of the different visibility and visual comfort factors into ratings of a mathematical type will be basic.

Charles W. Prisk, U. S. Bureau of Public Roads, and Director of the Highway Safety Study (June 12, 1959): I have only had time to examine the papers briefly, but I do feel that working toward the measurement of the relative seeing effectiveness of various systems is desirable.

Outdoor Laboratory Evaluation of Visual Comfort. Conducted at Hendersonville, N. C. Results reported at the I. E. S. National Technical Conference, on September 10, 1959, indicate that test data on visual comfort is consistent with computed (2, 4) relative visual comfort ratings. This conclusion is reached after two years of outdoor full-scale testing of a typical roadway lighting system using an evaluator developed on request by S.K. Guth (33, 34).

The selection of observer (3) data produced by the extensive outdoor studies was based on an indoor BCD "population study" conducted by J.S. Franklin in the Photometric Laboratory at Hendersonville. The latter data is in agreement with previous studies (35, 36). Figure 8 shows an observer making an outdoor relative visual comfort evaluation. The lighting-roadway system being observed is shown in Figure 9.

The Guth evaluator may be used to demonstrate and provide better understanding of the fundamentals involved in improving relative visual comfort. A driver-observer, sitting in an automobile, readily adjusts the brightness of the flashing comparison source to the BCD, borderline sensation between comfort and discomfort. By changing the lighting, the driver can observe and readily appreciate the fact that the BCD brightness for a roadway lighting system increases with appreciably higher field brightness, including the brightness of the pavement background against which the flashing comparison source is being viewed.

An increase in field brightness (including pavement) improves the relative visual comfort ratio unless accompanied by a corresponding increase in the combined brightness of the system luminaires. The latter may be increased within the limits of the relative comfort ratio without decreasing the relative visual comfort. The evaluator demonstrates that progress involves higher brightness at or near the pavement level with lower brightness up at the luminaire mountings.

Wilbur S. Smith, Consulting Engineer, has offered a discussion of the IES paper, which in addition to stating the fact that "comfort is a principal objective in all highway transportation," also includes the following excerpts:

> Certainly, highway officials and others are in dire need of a better means of objectively determining the optimum amount and type of lighting given for surface and traffic conditions. It is the desire of highway engineers to utilize roadway lighting as a means of improving traffic services and safety on major highways; yet, they do not have a method of evaluating different types of lighting and lighting installation by generally approved and accepted methods.
>
> ...Better means of objectively measuring highway lighting systems would probably be one of the most effective means of encouraging and justifying the more widespread use of highway lighting on expressways and other major highway facilities.

European Ratings and Studies. At the C.I.E. International Commission on Illumination, quadrennial meeting held at Brussels, Belgium, during June 1959, several reports (23, 24) were presented showing how their accelerated progress has brought about adoption of visibility and visual comfort criteria. An extensive full-scale demonstration of different roadway lighting systems, near Brussels, afforded the delegates visual proof that an effective and pleasant lighting installation combines adequate pavement brightness with a low cutoff of candlepower distribution.

More recently at Hendersonville, also at the I.E.S. Technical Conference, L. Gaymard (30), Street Lighting Chief Engineer for Electricite de France, reported on the widespread public enthusiasm for the continental European roadway lighting practice of low cutoff luminaire, 40-ft mounting heights and moderate spacings.

In addition to previous references to European practice and studies:

a. Much of continental European practice is based on extensive studies conducted on a full-scale outdoor laboratory provided by the Philips Company at Eindhoven, Netherlands.

b. Relative visual comfort (their terminology is discomfort glare) is evaluated in terms of pavement brightness, such as: "the average luminance (brightness) of the road surface necessary to reduce the discomfort glare to a satisfactory degree." This is similar to the preceding conclusion (2) regarding studies at Hendersonville using the Guth evaluator.

c. The visibility studies by de Boer and associates have been based on: "25 actual installations as well as in the outdoor laboratory. For test objects in these experiments Landolt-rings were used having a diameter of 0.16 M and a reflection factor of 9 percent."

These dimensions and reflectance values are quite similar to those of the target used in the computation (2, 4) of relative visibility. The dynamics of observers traveling along the test roadway in automobiles was included in the de Boer visibility studies.

d. Waldram's report for the International Committee on Street Lighting says: "In the U.S.A. the importance of luminance (brightness) is becoming recognized and the possibility of specifying it has been discussed."

e. The British Ministry of Transport has done considerable work on studies of pavement reflection characteristics and some studies of traffic operations, particularly from the standpoint of night accident prevention. They have been quoted as saying that United States accident data is not comparable in detail and engineering analysis with similar work that has been done in Britain.

The foregoing and the detailed reports of diligent accelerated foreign work on roadway lighting should be seriously considered by people in the United States, who are interested in, or affected by, night motor vehicle transportation.

New Requisite Visibility-Brightness Studies by H.R. Blackwell.—H.R. Blackwell and associates (Messrs. B.S. Pritchard, R. Schwab, D.F. Fisher, and J.G. Omhart) of the Institute for Research in Vision at Ohio State University have a very high quality scientific interest in contributing to the effectiveness of roadway lighting. At the September 1959 I.E.S. Technical Conference the Blackwell-Pritchard team presented an informal (22) paper reporting their preliminary studies of requisite roadway lighting. These studies were initiated during April 1958 and are expected to continue during 1960.

Blackwell's work on roadway lighting is being sponsored by the Illuminating Engineering Research Institute at the request of the IES Committee on Roadway Lighting. He has developed a system for evaluating the requisite brightness for seeing various objects on the roadway when the driver has a time interval of one-fifth second for perception under dynamic moving eye conditions. It is expected that a new scale of relative visibility and the visibility ratings required for representative night driving conditions is likely to be available during 1960.

The Blackwell studies use a new instrument called the Visual Task Evaluator (21) developed jointly by Blackwell and Pritchard.

It is hoped that the requisite level of brightness, and visibility which evolves from Blackwell's studies may be accompanied by a method for rating, relatively, the effectiveness of other lighting. The requisite level of visibility may be established as a datum or reference for comparison of less or more effective methods of producing visibility. Specific roadway lighting systems will provide visibility effectiveness which is higher or lower relative to the datum or requisite level.

Thus, relative-to-requisite ratings would be useful as a measure of how good lighting may be for visibility effectiveness. It is also hoped that the requisite level of relative visibility which evolves from the Blackwell roadway lighting studies can be correlated with the scale of the Luckiesh-Moss visibility meter which is relative to threshold or bare discernment.

It is obviously desirable to have and use a single number rating for net relative visibility instead of using two ratings, such as the factors: pavement brightness, and the percent visibility loss due to disability veiling brightness.

Additional Comprehensive Evaluations Are Desirable.—There are many indications as to the need for comprehensive evaluations of roadway lighting, including those pointed up by the Armed Forces, N.R.C. Committee on Vision (37), and the HRB Night Visibility Committee (38) as well as the Highway Safety Study.

Dynamics is a typical night driving condition involving high-speed movement of both the object to be seen and the driver-observer. The actual effect of dynamics on night visibility with or without roadway lighting should at least be estimated and included for rating purposes.

Fatigue, tension, preoccupation of the driver's attention and sense capacity with tasks other than seeing, typical of night driving with or without good roadway lighting, should be at least estimated. It is hoped that the $800,000 Harvard Medical Research project (39) on causes of accidents will provide some answers. Also the G.S.R. driver tension and similar studies by the U.S. Bureau of Public Roads might well be extended to include night driving conditions including good roadway lighting.

Factors involved (4, 22) in ratings for roadway lighting effectiveness should be measured, evaluated, interrelated, and conclusions published for general use. Relatively simple examples are percent loss of visibility due to typical fluctuations of DVB, full-scale measurements of pavement brightness, and reflection characteristics of representative pavement surfaces, evaluation of the effect of transitional brightness-adaptation, etc.

Instrumentation Recently Developed for Field Measurement of Seeing and Traffic Factors

New instruments for field measurement of the seeing factors in roadway lighting have been developed in the United States. These measurement devices should be put to use to provide additional data on the visual effectiveness of roadway lighting.

Action programs may involve measurements of existing roadway lighting installation, outdoor laboratory studies, and indoor simulator studies. Foreign instrumentation available for evaluation of roadway lighting should be investigated. Any that are adaptable to U.S. studies of roadway lighting effectiveness should be used even if the purpose involves only the correlations essential for an International Code or Recommended Practice for Roadway Lighting.

Recent United States developments include:

1. Pritchard brightness meter.

2. Fry-Pritchard meter for disability veiling brightness, (DVB).
3. Blackwell-Pritchard visual task evaluator (V.T.E.).
4. Finch visibility meter.
5. Comparison of visibility measurement systems.
6. Guth evaluator for rating the relative visual comfort of roadway lighting systems.
7. U.S. Bureau of Public Roads instrumentation for operations and driver response.

Pritchard Brightness Meter.—B.S. Pritchard has recently developed and made available an instrument which is suitable for the brightness measurement of small areas corresponding to the size of objects and surfaces when several hundred feet ahead of the driver-observer. This meter has the additional advantage of a physical scale reading, which does not require photometric balance by an experienced observer.

This instrument is being used for outdoor measurements (22) of the pavement brightness or object brightness factors in visibility, or discernment (as listed in Fig. 5), and described in Appendix A of A.S.A. Practice (9).

Fry-Pritchard Meter for Disability Veiling Brightness (DVB).—The DVB, or disability veiling brightness of roadway lighting systems, may now be integrated and measured using a new instrument developed by Fry (41) and Pritchard. Their work has been sponsored by the Illuminating Engineering Society Research Institute. Mounted at the driver's eye position in an automobile, the combined brightness in the field of view at successive driver positions in a lighting system may be readily measured by a physical scale reading similar to that of the aforementioned meter for pavement brightness.

Instrumentation or computation is essential for this purpose. The reduction in visibility due to DVB may be described as you-don't-see-as-well-as-you-think-you-do. Correlations should be provided in addition to those presented in previous papers (2, 4, 5, 6, 7, 14, 15). This percent loss data should include at least an estimate of the increase in loss resulting from the fluctuation due to the driver's movement along the roadway at representative speeds. As mentioned in the papers, the data used included an estimate by Reid-Chanon for 25-40 mph vehicle speeds.

Field brightness or the combined integrated brightness in the driver's field of view (2, 3, 4, 35, 36) should be measured for relative comfort evaluations (Fig. 5) using the basic instrumentation described under "Pritchard Brightness Meter" and "Fry-Pritchard Meter for DVB."

Blackwell-Pritchard Visual Task Evaluator (V.T.E.).—Crouch, Secretary of the Illuminating Engineering Research Institute, described (43) this instrument now being used for studies of requisite roadway lighting effectiveness (22) as follows:

> The Visual Task Evaluator is a portable piece of equipment built around a complex optical system. It is the function of the equipment to equate the visibility of a practical task to the visibility of a circular target for which illumination requirements have been established through research.
>
> To accomplish this, the practical object to be seen is placed within the instrument's view. The instrument is then adjusted so that the most important detail of the task object is at threshold—or just barely visible. Without changing the setting of the instrument, the image of the practical object is replaced by the image of a circular target, also reduced to threshold.

Finch Visibility Meter.—D.M. Finch of the University of California and the Institute for Traffic and Transportation at Berkeley has developed a readily portable visibility meter (40) which combines several features. This instrumentation has not been made available for use by others. However, one of the components used in the Blackwell V.T.E. resulted from the Finch meter development.

Comparison of Visibility-Measurement Systems.—It is obviously desirable to evaluate and correlate the features and/or data obtained using visibility meters available here and abroad. At the 1959 I.E.S. Technical Conference, Arthur A. Eastman and Sylvester K. Guth presented a paper (44) comparing the results obtained with the Luckiesh-Moss visibility meter (42) with data based on use of the V.T.E.

Correlations such as this should be extended to include roadway lighting visibility conditions and relative ratings pertaining thereto.

Guth Evaluator for Rating the Relative Visual Comfort of Roadway Lighting Systems.—The evaluator developed by S.K. Guth and J.B. McNelis is an aid to outdoor full-scale rating of effectiveness of roadway lighting systems in terms of relative visual comfort (2-4). Uses of the evaluator are shown in Figure 6 and Figure 7. This device is also valuable for indoor studies (33) and evaluation of simulated conditions (3).

The visual comfort rating is relative to the motorist-observer sensation which would be at BCD, the borderline between comfort and discomfort for the lighted roadway. The evaluator BCD brightness, $\bar{B}_L$, is on the observer's line of sight and excludes the combined brightness of the system luminaires. The brightness comparison providing the evaluator rating at each motorist-observer viewing position is:

$$\text{Evaluator Ratio at each position} = \frac{\bar{B}_L}{B_L}$$

in which $\bar{B}_L$ is the brightness of a source on the observer's line of sight which is at BCD sensation brightness with respect to the lighted roadway background excluding luminaires (fL) and B_L is the brightness of a comparison source on observer's line of sight which produces sensation equivalent to the combined brightness of the system of luminaires (fL).

This evaluator may be used to demonstrate and provide better understanding of the fundamentals involved for improvement of relative visual comfort ratings for roadway lighting systems. This may include an appreciable increase in pavement brightness.

U.S. Bureau of Public Roads Instrumentation for Traffic Operations and Driver Response.—The U.S. Bureau of Public Roads are congratulated for their development of the mobile Traffic Analyzer which records traffic operation field data in digital form. Also the GSR (galvanic skin reflex) meter is being used for measuring driver tension responses.

It is expected that these new instruments will be put to more extensive use in the immediate future. Such other instrumentation as may be required should be developed during 1960. The measurement of night traffic and human-driver factors is highly significant in evaluating the effectiveness of seeing factor improvement as produced by good roadway lighting.

SUMMARY

Although some significant progress in roadway lighting developments is being made, it should be readily apparent that much more data accumulated and presented at a greatly accelerated pace is now essential. All those interested in, or affected by, night motor vehicle transportation should be vigorously initiating and supporting evaluations of the benefits of roadway lighting. The potential improvement in public welfare is an impelling obligation.

The night traffic benefits should be obvious; yet might well be further documented by engineering estimates, appraisals, and measurements where practicable. Ratings for night traffic benefit can now be based on seeing benefit ratings for the roadway lighting involved. Correlation of night traffic ratings with relative visibility and relative visual comfort ratings for the effectiveness of roadway lighting will indicate how good the lighting must be for the desired public benefit.

Visual benefit ratings will also implement attention to the technological details by which the seeing effectiveness of roadway lighting will be improved in the future. Additional visual data, studies, and presentations of knowledge are imperative.

Action by many people is urgent. Interest in accomplishment for improvement in night motor vehicle transportation is widespread in the United States and abroad. Freedom to drive at night with assurance, pleasure, and efficiency involves objectives which warrant the combined use of the best research, talent, facilities, and engineering skills.

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EXCERPTS FROM NETHERLANDS' RECOMMENDATIONS ON PUBLIC LIGHTING—MAY 1959

TABLE 2.1. Recommended values of road surface brightness and its irregularity

Road or Street		Average road surface brightness in cd/m²	(in) (footlamberts)	Highest permissible irregularity in the brightness pattern, expressed as the ratio of the greatest to the least brightness on any line across the road as well as the ratio of the average brightness to any minimum in the road picture.
				Ratio
Roads for fast traffic	Outside built-up area:			
	Road reserved for motor traffic	2	(0.6)	3
	Trunk road	1.5	(0.45)	4
	Important main road	1	(0.3)	4
	Inside built-up area:			
	Main thoroughfare	2	(0.6)	3
	Access road (Arterial road)	2	(0.6)	3
Street in industrial or dock area		1	(0.3)	5
Quay, wharve lock or bridge over important waterway		1	(0.3)	5
Shopping street with road traffic		1	(0.3)	5
Shopping street without important traffic		0.75	(0.22)	8
Residential street with road traffic		0.75	(0.22)	6
Residential street without important traffic		0.5	(0.15)	10
Fashionable square or promenade		0.5 to 2	(0.15 to 0.6)	-

"Cutoff luminaires, either low angle or medium angle, are generally used in the Netherlands."
(Note: Material in parenthesis added by C. H. Rex to put in terminology used in U. S. A.)

Appendix B

(FROM REPORT OF PROGRESS IN STREET LIGHTING 1955-1958, BY J.M. WALDRAM, CHAIRMAN COMMITTEE W-3.3.1 C.I.E. INTERNATIONAL COMMISSION ON ILLUMINATION)

"The following table indicates the ranges of mean illumination and mean luminance adopted in the various codes under review . . . . . . Nearly all codes pay special attention to glare, which is regarded as a particularly important blemish upon an installation, and in most cases advocate some form of cut-off lighting."

Table I

Country	Mean Illumination		Mean Luminance (Brightness)	
	Lux	lm/ft²	cd/m²	ft. L.
Finland	3-9 (mod. Pedestr. traffic)	0.3-0.9	0.3-0.85	0.09-0.25
France	2.30 (on dark surfaces)	0.15-1.5	Not less than 0.5-0.15	
Germany	0.5-16 or 20 (on dark surfaces)	0.05-1.6 or 2	0.03-1 or 1.3 (calculated)	0.01-0.3 or 0.4
Gr. Britain				0.2-0.7
Netherlands			0.5-1 or 2	0.16-0.31 or 0.6
Spain	0.5-0.8 to 9-12 (5 classes)	05-.08		
Sweden	3.7-5.1; max. 10	0.37-0.5; max. 1	0.35-0.5, max. 1 (calculated)	0.11-0.15, max. 0.3
Switzerland	Not less than 6	Not less than 0.6		
	Min. Illumination			
U.S.S.R.	0.2-6	0.02-0.6		

Explanatory notes inserted by Charles Rex:

(Luminance is our photometric brightness as we apply it to the brightness of pavement and objects.

"Not less than 0.5-0.15 footlamberts" as pertaining to the Code of Public Lighting for France should be of interest in revising our U.S.A. Recommended (ASA) Practice.

Suggest consideration of the phrase "not less than" instead of minimum, at any position on the traffic-used roadway and minimum in service at any time, etc.)

Appendix C

EXCERPTS FROM "THE FEDERAL ROLE IN HIGHWAY SAFETY," A REPORT SUBMITTED TO THE 86th CONGRESS, 1st SESSION, FEB. 27, 1959, by Lewis L. Strauss, U.S. Sec'y of Commerce

(House Document No. 93, available from Sup't of Documents, U.S. Government Printing Office, Washington 25, D. C., price - 60 cents)

This reports results of the Highway Safety Study conducted under the direction of Charles W. Prisk, U.S. Bureau of Public Roads.

P. 3 " . . . . new knowledge in highway construction is benefiting safety."

P. 4 "Modern design practices can also bring permanent gains in safety."

P. 5 " . . . , the most hazardous period in cities and rural areas alike is during the hours of 2 to 4 a.m. when the effects of natural fatigue, intoxication, and drowsiness are compounded by the lack of light. Nationwide, the fatal accident rate in these early morning hours is substantitally above that of the most of the other dark hours throughout the night and is at least six times that of the more favorable daylight hours."

P. 6 "Cost of traffic accidents

(a) Total cost.--The total cost of traffic accidents, including property damage, wage loss, medical expense, and the overhead cost of insurance, is estimated at up to 1 cent per mile of travel, an approximate equivalent of 12.5 cents on each gallon of gasoline consumed for highway purposes. The total economic loss to the Nation is estimated by the National Safety Council at $5.4 billion for 1958. Other estimates are higher.

(b) Direct cost.--An intensive study in one State disclosed that direct out-of-pocket cost is 0.43 cent per vehicle-mile. Especially conspicuous among the major findings from this study reported is the division of the direct-accident-cost dollar ($0.05/gal. gas): 40 cents is incurred for property-damage accidents, 57 cents for injury accidents, and 3 cents for fatal accidents. While human loss through fatal accidents cannot be adequately measured in cold terms of dollars and cents, the fact that fatal accidents account for but 3 percent of the total direct economic loss clearly shows that consideration of the total accident problem should not become obscured by attention to this aspect."

P. 8 " . . . . The nature and proportions of the highway safety research need are such that the required work cannot be readily undertaken and supported by private interests, universities, or to more than a limited extent by the States and cities."

P. 9 " The Board should coordinate all official Federal traffic-safety programs and all research activities of the Federal Government in the field of traffic safety. It should seek the advice of State and local highway and traffic officials in carrying out its responsibilities and should encourage the application of the results of research in the safety programs of State and local agencies by cooperation directly with those agencies or through their official organizations . . . . "

P. 29 "Most presentations on the cause of the highway accidents assign responsibility for 9 out of 10 accidents to the driver . . . "

"This assignment may have some value in the promotion of safety consciousness, but it is of doubtful validity in any broad study of the traffic-accident problem. If responsibility for cause is interpreted to mean any amount of contribution, then the driver becomes 100 per cent involved since obviously no action takes place on the highway except of his instigation. . . . . . "

"Thus the driver is often believed to be the principal medium for the improvement of highway safety and yet there is less critical knowledge about him than is known about either of the other two elements. It has been stated that vast sums have been spent on vehicle development, and that highway research though less than adequate has been impressive, but that the real gap in our knowledge is in the understanding of human factors."

P. 30 ". . . . Thus, there is a very fundamental interrelation between driving and the driver, and the ways in which the demands of the task are adapted to the characteristics of the human being will be a determinant of the safety and efficiency with which the highway-transportation system will function. It is, therefore, very artificial to view the human factors as something distinct and independent of the system in which they must operate."

"In contrast to the effort expended on such things as reaction time and eye tests, relatively little experimental research has been done on the more fundamental factors of perception, judgment, analysis, decisionmaking, etc. . . . . . ."

P. 31 "Thus, it is well known that the human being has definite limits in the amount of information he can utilize per unit of time. . . In all of these areas of fundamental importance to highway safety, little research has been carried out. It does seem apparent, however, that the very nature of the driving task often forces the driver to the very limits of his capacities, thereby increasing the possibility of accident - producing responses."

". . . . In long-distance driving, loss of vigilance may become an important factor in driving errors. "

"Fatigue is also a common consequence of extended durations of driving, and may contribute as much as monotone to loss of vigilance. Fatigue has not been clearly defined, especially with reference to highway safety, but it usually
P. 32 refers to the decrement in performance due to depletion of energy reserves-- either physiological, psychological, or muscular. . . . . ."

". . . . Although little work has been done on automobile drivers, skill fatigue may be a fundamental contributor to accidents."

P. 52 "The investment involved in the planning, design, and construction of a highway dictates that it serve traffic for a substantial period of time. The highway itself is the one permanent structure of highway safety, working 24 hours a day every day in every year to fulfill its public-service function. Obviously, this has both advantages and disadvantages. The highway hazards that are built in, without sufficient regard for human engineering principles, endure in their effect as persistently as do the features that improve safety. . . . . ."

P. 53 ". . . . but because the States recognize that these standards are based on the results of extensive research and sound engineering judgment gained through long years of experience."

"These new standards are the nurtured product of long experience and research, including countless observations and analyses of traffic performance and driver behavior, key factors in safe highway design."

P. 55 "Comfort, convenience, and safety are considerations of importance equal to a consideration of capacity, in today's highway planning. This concept of adequate facilities requires modern techniques for handling traffic with clear unmistakable signing, marking, and other controls so that all highway facilities, old and new alike, will function properly. . . . "

P. 64 "STREET and HIGHWAY LIGHTING"

"The use of street lighting is a widely accepted practice in urban areas, especially where traffic congestion and pedestrian movements are heavy. Non-traffic benefits are also readily appreciated. These include a sense of public comfort and convenience and the deterrence of crime."

"Comparative studies in numberous cities have shown that urban lighting tends to produce highway safety gains. Often the comparisons have been limited by a lack of scientific controls and by the fact that the lighting was installed as a part of a larger improvement program. Considering all advantages to the driver and the other social advantages, it can be concluded that modern street lighting, adequately designed and operated, does improve safety in most city situations. By present standards, many urban street-lighting systems are outdated, inadequate, and poorly designed. Modernization programs are active, and the progress is geared principally to the availability of funds, as well as to the relative importance attached to street lighting as against that of other public works."

"The continuous lighting of rural highways has not been undertaken on an extensive scale since no substantial facts are available to show that the cost is justified. Lighting for a specific purpose and usually at specific locations is more common and has proved definitely beneficial to safety. Typical advantages cited include the identification for the motorist of critical roadway features farther ahead, minimization of headlight glare, and improved driver judgment of speed and direction of travel of other vehicles. "

"Lighting of rural highways has not been as generally accepted as for city conditions because the benefit-cost ratio has not been established to be as high as that of other needed improvements. In this connection, more intensive studies are warranted to understand better the safety effects and economics of rural highway lighting. A recently opened freeway, continuously lighted over a substantial mileage, has furnished the first opportunity for such research. The Bureau of Public Roads has initiated appropriate cooperative studies with State authorities

P. 72 . . .An accident involvement, very simply, is one driver or one vehicle involved in one accident. The accident involvement rate, then is the number of involvements that occur for every 100 million miles of highway travel . . . . . . "

P. 75 Note Figure 7.

P. 79 Note Figure 10.

P. 80 Note Figure 11.

P. 81 "It is significant that passenger cars had a nighttime involvement rate nearly three times as great as their daytime rate . . . . . "

P. 84 " . . . Enthusiasts for highway illumination often ascribe the difference chiefly to darkness, per se, but this is a misleading oversimplification . . . . "

"Fatigue, intoxication, higher speeds of travel, and other factors probably all contribute to the extremely high fatal-accident rate during the hours shortly after midnight, although darkness presumably compounds some of these difficulties for nighttime drivers. Only carefully planned research can determine and measure the contribution of the factors involved and point the way toward night accident reductions."

P. 85 Note Figure 15. (P. 84-"Figure 15 presents evidence based on travel miles of exposure and suggests that additional factors are involved."

P. 93 "... To fulfill the primary aims of the study looking toward identification of bona fide accident causes, wholly new techniques for scaling and isolating the basic variables must be developed or adopted. Thus, the intensive investigation of accidents is being expanded to include development of measures and criteria for a new series of factors. As an example, driver vision is customarily measured by a static test, which has not reliable association with the visual demands upon a driver or object in motion at the time of accident. Means need to be found for improved measures of dynamic visual acuity, of meaningful components of the perceptual fields, and of the driving process."

P. 108 "Vision problems... Dynamic visual ability has been identified as having special significance for safe driving."

"....Similar research on lighting of highways, bridges, and tunnels, and other light adaption problems has been or is being conducted by the Bureau of Public Roads in cooperation with State Highway Departments and others as a means of developing adequate policies for the facilities new in construction."

P. 114 "Other work planned, --In addition to current research in highway safety, the Bureau of Public Roads is considering plans for new research aimed toward selected areas where more knowledge is criterically needed. Proposed projects include investigation of monotone and fatigue problems in expressway driving, more intensive analysis of the driving process, application of human engineering principles to highway design and operation, improved units for accident exposure, development of more complete and accurate accident reporting, and improved means for communication from the highway to the driver and among drivers."

P. 169-171 Note participation of Automotive Safety Foundation.

P. 173 Note questions.

P. 198 Note in "Table I--Classification of elements characterizing the accident process

1. Road situation: Physical environment within which the man and vehicle operate.
   Factors and their operation

   Stable - #3. The lighting on road in terms of such factors as appropriateness, intensity, color, and patterning.

   Variable-#2 Visibility as influenced by night and day cycles.

Excerpted by Charles H. Rex - 5/27/59