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Highway Lighting and Accidents in Indiana

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● ALTHOUGH Webster defines a tool as "an instrument of manual operation," in this automotive age a traffic safety "tool" may be defined as anything that can be used to prevent traffic accidents and facilitate the moveme of our ever-increasing vehicular volume.

Reduced to its simplest form, traffic accidents involve people: people injured, people mained, and people killed.

The statement, "We will kill at least one unfortunate traffic victim next year during the hours of darkness at the intersection of US 52 and US 421 (16th Street and Northwestern Avenue)," was made in 1950 at a meeting of aroused traffic safety-minded citizens and public officials in Indianapolis. This statement was based on an analysis of the traffic accident investigation records of the Indianapolis Police Department. It was startling to see the same location appearing as a fatality location year after year. The unanimous reaction to the statement, as could be expected, was "do something about it."

Today, many traffic tools are being used in the efforts to spare people from death, suffering, and disability on streets and highways. Improved road design, divided highways, one-way streets, channelization, truck lanes, left turn lanes, interchanges, signs of all types and descriptions,traffic signals, flashers and directional arrows are familiar to all. There are many more traffic tools that could be mentioned, traffic tools that are used to advantage in Indiana, but none of the traffic tools mentioned or used had the slightest value if drivers cannot see to use it. Sight, the most precious of the five senses, is worthless without light. The sun furnishes 10,000 footcandles of illumination during the day, but, at night, our forefathers discovered that the moon furnished an inadequate amount of illumination, and they placed torches and tapers in front of their homes.

There are now two principal ways of aiding the ability to see in traffic and on highways at night.

One of these methods is the use of automobile headlights. The sealed-beam headlight, recently adopted by Indiana, is a tremendous improvement, especially when driving with the depressed beam. Even so, the majority of people today are generally over-driving their headlights—driving too fast for any factor of safety reaction time.

The second method is proper and adequate street and highway lighting. This method is a proven and important tool for traffic safety, but it is no cure-all, in any sense of the imagination, and should not be considered as such.

The elements of safe seeing (visibility required to locate and identify) are pavement brightness and obstacle brightness. Pavement brightness, or uniformity of background, is necessary for silhouette contrast. Obstacle brightness, which makes surface details visible by direct lighting, is actually more reflectivity from the object than from its background. The absence of glare, the light which is in such contrast to the surrounding area that it actually causes a reduction of visibility, is one more important element.

In Indiana, street or highway lighting is thought of as traffic safety lighting. Many reasons explaining the benefits of proper traffic safety lighting, have been cited but it is generally felt in this area that the most important of these are to assist in the reduction of accidents and fatalities while facilitating the movement of traffic; to assist in the curbing of crime, thus providing additional protection for the general public; and to promote civic progress and community pride, hence helping business in general.

Traffic safety lighting should be installed only when needed and in those locations indicated by night traffic accident statistics. In this manner, the tax dollar is most wisely spent for the most gain. Crime areas, as pointed out by arrest maps and charts, can also indicate locations for traffic safety lighting installations. On one small section of a highway in Indianapolis, armed robberies decreased 75 percent in the year following the installation of modern lighting. It is also interesting to note that, at this same location, the rate of drunks arrested increased by a ratio of eight to one in this same year. No street or road widening project in congested areas is complete unless adequate traffic safety lighting is also provided. Any traffic pattern change, such as a one-way street or highway, invariably requires street and highway lighting changes to provide proper traffic and pedestrian safety.

There are many items to consider in the proper design of traffic safety lighting. A few of these are street and highway widths, spacing of lighting units, mounting heights, vehicular traffic conditions and patterns, pedestrian activity, and area problems. What light source should be used, incandescent, sodium vapor, mercury vapor or fluorescent? Incandescent lighting is a general purpose source and is the most widely used. The sodium vapor source should be used only for dangerous and hazardous locations to obtain its most effective results. The mercury vapor source is widely used for streets with heavy traffic. Certain objections to its color distortion have been overcome by color-corrected mercury lamps. Fluorescent lighting, the most recent source for street and highway use, has the least glare, allowing its use in underpasses and tunnels, as well as on streets and highways.

But, what of highway lighting on Indiana's 85,179 miles of state and county roads where a traffic crash occurs every six minutes, a traffic injury every sixteen minutes, a traffic death every eight hours, and where over 100 million dollars is lost each year? Is this traffic safety tool being used to advantage? Did street and highway lighting contribute to Indiana's outstanding traffic record of saving almost 200 lives in 1954 and almost holding this gain in 1955, despite the increased vehicular miles driven and approximately 79 percent of the total traffic fatalities occurring in rural areas?

By reviewing the history, of highway lighting in Indiana, a determination of its present standing can be made. The State Highway Commission Ace of 1937 provided: "The State Highway Commission is hereby authorized and empowered, whenever such commission deems it advisable for the safety of traffic, to illuminate dangerous curves and intersections on the highways in the State Highway System, and also the bridges of such system. The cost of the installation of such lights, may be paid out of the funds appropriated to said commission for 'miscellaneous service' and the cost of maintaining such lights shall be paid out of the funds appropriated to said commission for the 'maintenance of highway'."

In the latter part of 1937, the first highway lighting under this act was installed on US 20, near Michigan City. Approximately one mile of lighting was placed along a section of roadway with a high frequency of fogs and night accidents. To this day, a better night accident record than any section of US 20 across the entire state has been maintained, although the lighting is actually inadequate for present traffic conditions and vehicular volume. These lights were installed and have been operated and maintained by the local utility company.

In the following years, as is often the case, very little additional lighting was installed, but state officials recognized, in 1949, the safety possibilities of highway lighting. Knowing the accomplishments in Indianapolis, they began to plan for new installations. However, certain state officials felt that the Highway Act of 1937 did not provide full and clear authority for continuous lighting installations. Consequently, an attempt was made in the legislature to amend the 1937 Act by inserting: "Said Commission is further authorized and empowered to illuminate any portion of a highway or highways in the State Highway system outside incorporated cities and towns, where, in the opinion of said Commission the character and density of traffic require such illumination for the safety of the public."

Unfortunately, the amendment was introduced in the latter part of the 1949 legislative session, and, although reported out of committee favorably in the House of Representatives, it was caught in a last minute legislative jam and was never acted upon by the house members. In 1951, the same bill, with a preamble aimed directly at a particularly dangerous section of Indiana 40 outside of Indianapolis, was introduced and became House Bill 98. It was passed in the House of Representatives with only one dissenting vote and unanimously in the Senate. It is well to emphasize the fact that this bill, while clarifying the situation with respect to continuous lighting, does not provide the State Highway Commission with the power to illuminate sections of roads or highways within the corporate limits of cities and towns. It is felt that the cities and towns should provide their own tax funds for such lighting. It can be readily seen that, in many instances, the lighting requirements within cities and towns are much greater than those required for the lighting of highways in less congested urban areas, and the light level is often above that required for traffic safety. However, the state can still illuminate isolated or specific locations within the corporate limits of cities and towns should it so desire, and, in a number of locations (particularly in Indianapolis) it has done so.

Oddly enough, the section of Indiana 40 referred to in the preamble of House Bill 98 has never been illuminated. The lighting project was not ordered until the latter part of 1955, and is now being installed by the Indianapolis Power and Light Company.

For a number of years, there has been in existence in Indiana, a Highway Lighting Committee, representing the Indiana Electric Association, an organization composed of six privately-owned utilities. Members of this committee are experienced lighting engineers and their respective companies blanket the entire state. In 1951 and 1952, this committee began to work closely with engineers of the Division of Traffic of the State Highway Departmtne. As a result, several minor lighting installations were completed.

The services of this Committee were also requested by the Indiana State Police to lay out and design proper lighting facilities at 17 truck load weighing stations at check points scattered throughout the state. The purpose of these lighting installations was to protect the police personnel and to provide visibility for truck drivers entering and emerging from the load weighing zones. The success of these lighting installations, which averaged approximately 15 lights each, developed an immediate interest in highway lighting among the members of the State Police organization.

The 1953 Indiana General Assembly, through House Bill 74, established the Office of Traffic Safety, which began its operations on May 1, 1953. This office is administered by a Director of Traffic Safety appointed by the Governor and is responsible for the development and conduct of an effective statewide traffic accident prevention program. Major duties of the office include working closely with the various governmental departments and agencies on the development and conduct of effective traffic safety activities and coordinating these activities into a strong attack on the traffic accident problem. The services of the Highway Lighting Committee were immediately offered to the Office of Traffic Safety; and, after several meetings, the committee met with engineers of the Division of Traffic and developed jointly a highway lighting program for Indiana. This program is based on the principle of providing proper and adequate illumination in those sections of highways where state police traffic statistics indicate a definite need for highway lighting. This principle insures the prudent use of the state tax dollar and essential immediate protection to the motoring public in those locations where the most benefit should be forthcoming.

After considerable study, it was decided that highway intersections, bridges, dangerous curves, dead ends, traffic interchanges, underpasses, railroad crossings, and congested approaches to cities and towns should receive priority treatment since they constituted the major traffic hazards for which lighting would prove most beneficial. According to state police statistics, there was a total of 30, 760 accidents in rural areas in 1954. These accidents were broken down as follows: daylight 18, 292; dusk 1, 242; dawn dawn 367; darkness, with street lights 174; darkness, without street lights 10, 672, and not stated 15.

The statistics indicated that 40 percent of all the accidents in rural areas occurred at night, with only an estimated one-third of the traffic volume flowing. They also indicated that 50 percent of all rural accidents in which one or more fatalities occurred were also at night. Twenty-three percent of all rural accidents occurred at intersections, and 4½ percent occurred at railroad crossings, bridges or underpasses.

Adequate night visibility and protection at minor intersections, such as a county or local road and a highway route, can often be accomplished by simply installing two overhead lights. However, major intersections and crowded areas are considerably more complex. There are two basic factors which must be considered: average vehicular speed and average eye adaptation time. They can actually determine the required length of lighting to provide adequate traffic safety for the motorist. The adjustment of the pupil of the eye while driving with headlights on a highway and entering or leaving a lighted area is of extreme importance. For example, consider the effect on eyesight when one enters a lighted room from a dark area or the reverse situation. Until eyes can properly adjust themselves to the changing light conditions, vision is temporatily impaired. On a highway, that instant may be one's last. In a period of three years, in a one-block section of Indiana 40 in Indianapolis, there were five fatal accidents at night;

all were pedestrians crossing the street; all were killed by motorists traveling in the same direction.

Actually, the solution to the problem was childishly simple. Motorists had been traveling west on well lighted streets up to this particular block, and it was like driving into an inkwell; the drivers just did not see their unfortunate victims. Their eyes could not make the required adjustment. The lighting was improved, and there has been only one night fatality during the following eight years, in this particular block.

The general pattern adopted for lighting highways assumes a speed of 60 mph with 10 seconds of eye adaptation time. This means, for example, 880 ft of proper illumination will be provided in all directions from a highway intersection, beginning with a light level of approximately .5 footcandles and tapering up to 1 or 1½ footcandles at the road intersections. This level of lighting generally follows, or is better than, the "American Standard Practice for Street and Highway Lighting." Additional field studies and observations, following several installations of highway lighting, have revealed that speeds are lowered through lighted areas. Experiments are now being made with illuminated areas of 400 to 600 ft, based on approximate speeds of 45 mph and 10 seconds of eye adaptation time. This would mean that for the 60-mph driver a reduction in eye adaptation time to 5 - 7 seconds is necessary. Additional research on speed in lighted areas approaching intersections is planned jointly with the Traffic Division of the State Highway Department and the Road Research Division of Purdue University.

It is readily seen that, with less length of roadway to illuminate, the lighting cost will be reduced providing funds for additional coverage. Eye adaptation time is a problem, and Indiana welcomes information on the subject and ideas for practical research, since sufficient data for definite conclusions are not available at this time.

The 10,000 lumen incandescent lamp has been accepted, generally, as the lamp source and lamp size to be used for highway lighting service, since it provides versatility using the same equipment. If traffic increases, lamp size can be increased to 15,000 lumens, raising the light level but still using the same luminaire.

In certain circumstances, there are installations using other light sources, and the state plans to harmonize its lighting installations with those of the municipality in areas adjacent to cities and towns. All of the facilities are installed and owned by the companies or municipalities providing electrical service. These same agencies operate and maintain all equipment based on a flat-rate charge per light per year. Maintenance includes, of course, the replacement of all burned out lamps. Lamps are group-replaced at approximately one-half of the locations. The type of construction is uniform; the majority of the systems employing wood poles, using overhead wiring, and following standard street lighting construction standards. One exception to this is the traffic interchange at US 40 and Indiana 100, near Indianapolis, which will have metal standards and underground cable. Whenever possible, the poles are installed at a distance of 11 ft from the pavement edge. This permits the use of 12-ft and 16-ft mastarms to locate the lighting fixtures over the roadway proper. Mounting heights are usually from 27 to 30 ft above the pavement. In all instances, the installations are covered by written agreements (for terms of five years or ten years) and are executed on behalf of the State of Indiana by the State Highway Department. Requests for lighting installations are normally forwarded by the Traffic Division of the State Highway Department directly to the particular utility company serving the area.

In all cases, traffic statistics are obtained from the files of the State Police Department Accident Records Bureau and the Indianapolis Police Department Traffic Division. As an example, the statistics for a one year period covering that section of Indiana 40 referred to in the Preamble of House Bill 98 show that accidents by light condition were as follows: daylight 92; dusk 6; dawn 1; darkness, highway lighted 7; darkness, highway not lighted 71 with 5 fatalities. This represents a total of 177 accidents and five fatalities, analyzed in Table 1.

In the total reported accidents, five people were killed, 25 received severe injuries, and 70 reported minor personal injuries. The aggregate property damage was estimated at $55,000.00 over a twelve month period. The comments of the Accident Record Bureau were very pertinent: "Although 52 percent of the reported accidents occurred during the hours of daylight, night-time accidents on locations not lighted were ten times

TABLE 1

ANALYSIS OF 177 ACCIDENTS ON A SECTION OF INDIANA 40 DURING A ONE-YEAR PERIOD

Accidents				
Type	Number	Fatalities	Injuries	Property Damage
Collision with pedestrian	11	4	7	-
Collision with other vehicle	150	1	41	108
Collision with fixed object	2	-	1	1
Vehicle overturned	1	-	1	-
Ran off roadway	12	-	3	9
Other non-collision	1	-	-	1
Total	177	5	53	119

as frequent as those in lighted areas. Also all of the fatal accidents occurred during hours of darkness at locations not lighted. Since four of the five traffic deaths were pedestrians, it is reasonable to assume the visibility factor would rate high as approximate cause."

Highway traffic safety lighting has been installed or is on order for approximately sixty locations throughout Indiana. These installations vary in number of lights from one to 175 at a particular project. Approximately 500 highway lights are now installed and in service with another 300 in the process of being installed. All of these lights are being paid for by the State of Indiana on a flat-rate basis. In the majority of cases these lights are turned on and off by a photo-electric cell control. They are lighted approximately 4,060 hours per year. The average pattern at an intersection of two highway routes has been four lights at the intersection and three lights in each of the approaches to the intersection. For a total of sixteen lights, the spacing of the lights is usually staggered except at the intersection and gradually increases away from the intersection to a maximum distance of 175 ft.

Only a few of the isolated installations have been in service long enough to obtain reliable before-and-after accident information. However, the available results are interesting.

The intersection of Indiana 37 and 100 is located northeast of Indianapolis. It is a high-speed, signalized intersection, and it had a night record of four accidents and ten fatalities in a three-year period prior to lighting. In the four-year period following the installation of two overhead lights, there were six accidents at night and one fatality.

At one end of a new by-pass near Martinsville, Indiana 67 crosses Indiana 39 in a T-intersection. In a one-year period, four night accidents occurred—caused primarily by motorists over-driving the by-pass turn and being struck from the rear. In the one year following the installation of adequate intersection and approach traffic safety lighting, only two night accidents have occurred, although traffic has increased considerably. Neither of these accidents was caused by turning vehicles.

At the intersection of Indiana 51 and US 20 near Gary, there were three fatalities in eleven night accidents in the year prior to the installation of five lights. The following year, there was only one night accident.

The overall effect of the lighting program can be examined in Indianapolis, which is a city with 60 miles of state highway routes and approximately 500,000 population. In the last four years, 213 traffic fatalities have occurred on traffic, truck, and state highway routes with only 10 on strictly residential streets.

In 1950, there were 217,451 motor vehicles registered in Indianapolis. This increased to 266,154 at the end of 1954 with one car for every two people. In 1950, there was a total of 13,374 street lights. This total has been increased until there were 17,094 street lights as of December 15, 1955. In addition to the installation of 4,020 new street lights, 3,783 were replaced with modern lighting units and increased in lumen output. Night accidents gradually decreased. In 1950, there were 3,826; in 1951, 3,681; in 1952, 3,276; in 1953, 2,954; and in 1954, 3,029. Since a majority of the new lights and practically 100 percent of the modernized lights were installed (based on locations from police accident statistics), it is reasonable to believe that the lighting improvements were major contributions to the reduction in night accidents.

The Office of Traffic Safety has used $1,250 as the average cost per accident during 1954. By a simple application of arithmetic, it is readily seen that the accident reduction savings in dollars per year far overshadows the cost of this lighting program.

The decision to re-light the intersection of US 52 and US 421 (16th Street and Northwestern Avenue in Indianapolis) proved to be a wise one. In the two years prior to re-lighting this intersection, which carries a heavy rush hour traffic load in addition to normal state highway travel, there were 54 accidents during the day with no fatalities, and 60 accidents at night with 2 fatalities. Following the installation of proper lighting, the two year period had 53 day accidents and only 45 night accidents with no fatalities at any time.

South Street in Indianapolis is a heavily traveled, one-mile truck route with considerable night traffic. In one year prior to re-lighting, there were 71 night accidents with one fatality. The following year there was one fatality with only 45 night accidents.

A two mile stretch of US 52 and US 136 along 16th Street carries a very heavy volume of Indianapolis-Chicago traffic, and it passes through a small business area with used car lots and by the local ball park. The lighting in this area was modernized at an annual cost to the city of $5,900. In the year prior to re-lighting, there were 60 night accidents, but there were only 40 night accidents the year after.

The results of these and many other installations of traffic safety lighting over a period of years in Indianapolis have proven that proper street and highway lighting can save lives, injuries, and property damage.

One of the problems facing the highway engineer of today is that of unlighted trains crossing state highway routes. An increasing number of motorists are crashing into the sides of these trains. Such a problem existed on Indiana 67 at the Belt Railroad southwest of Indianapolis. In two years there have been 11 day accidents and 9 night accidents including one night fatality at this railroad crossing. A study revealed that the majority of the accidents at night were caused by motorists who were apparently over-driving their headlights and who usually skidded into the sides of the trains. The installation of one overhead sodium vapor light at this railroad crossing produced the following results in 1½ years and prior to the time a grade separation underpass was built: day accidents continued with a total of 10, but night accidents were reduced to 2. A study is now being made throughout Indiana as a result of this study, two overhead lights will probably be installed at many of the railroad crossings with high incidents of night traffic accidents.

Some amateur traffic experts believe that the effectiveness of flashers (in particular those which flash amber in one direction and red in another) is exaggerated.

They are a dangerous, often mis-used tool. A flashing light, regardless of color, even red, means "Caution, Slow Down," to an amazing percentage of drivers. At a recent state traffic meeting, one of the state legislators was asked what a flashing amber light meant to him and what a flashing red light meant. His answer was that a flashing amber light meant "Be Cautious" and that a flashing red light meant "Be Extra Cautious." Far too often a driver will stop at an intersection with a red flashing signal—only to pull directly in front of another car driving through the amber flasher. Flashers are often used for no other purpose than to indicate a crossroad with considerable turning volume. The same job can be done by the installation of two overhead lights, and the same warning as flashers (plus the advantage of visibility) will be provided in many cases at less cost.

In summary, here is a five-point program for traffic safety.

1. Strict enforcement of all traffic laws by a full complement of police traffic officers using all available enforcement tools.

2. Strict and impartial policy by all courts, with particular emphasis on repeat violators.

3. Removal of habitually reckless and dangerous drivers from the streets and highways.

4. Increased efforts by all individuals and organizations along every line of safety education and promotion.

5. Continuous application and use of all modern engineering, construction, and traffic facility improvements and tools.

Certainly, highway lighting is one of these tools.

Validity of the Night Sight Meter

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EARL ALLGAIER, Research Engineer, American Automobile Association

● SEVERAL devices for checking night vision have been proposed, built and their possibilities explored. One is an adaptation of the Glarometer which was used by Lauer (5) and others for measuring night driving vision. Sometime later, De Silva (2) developed a device which was made to resemble a roadway situation. The scale-size figure of a pedestrian was shown in a dark chamber, and the light was turned up until the subject could detect the image. A glare source was also set up to simulate oncoming light.

The Allgaier Shops in connection with the American Automobile Association then developed a Night Vision Meter which was designed to measure two aspects of night vision: seeing against glare and vision in low illumination.

About the same time, the American Optical Company developed the Adaptometer which was used for measuring the adaptation time of the eye after looking into a glare source. Like its more technical predecessor, the Biophotometer, the purpose was to determine the need for vitamin A by measuring time for adaptation to a given level of illumination.

Neither of these devices proved very practical for measuring motorists' vision, since too much time was required to make the tests. An advantage of the Glarometer is its ease of use, whereas the first device built by the American Automobile Association had the disadvantage of not differentiating sufficiently between persons to be of diagnostic value. Average scores constituted a higher percentage of the distribution than warranted.

Three phases of the problem seem to be of interest to psychologists, driver's licensing bureaus, and students of driving and traffic. One phase concerns the ability to see in darkness without glare of any kind. Some individuals seem to have greater ability to see in the dark than others. Some eyes seem to be better equipped with rods for night vision than others. Rods are supposed to function mostly for seeing in darkness or for what is known as scotopic vision.

The second concerns the ability to withstand glare from headlights of an approaching car; the effects of light on visual acuity and seeing efficiency; and, conversely, the amount of reduction in vision from a glare source.

The third aspect of this problem involves recovery time or how long it takes to see after passing bright lights. Some have estimated this to range from one second to 10 or more seconds, at least with a mean of about 2. 5 seconds. Others have minimized this phase of night vision. Practically, it is an important point, and traffic engineers have been interested in this phenomenon which they have called the "blind spot" after passing a car at night.

Allgaier (1) has recently developed and improved the original apparatus built by the AAA, which makes it possible to measure the three phases of night vision described. It is the purpose of this paper to present data on the validity of this particular apparatus and for each of these separate measurements.

PROBLEM

The reliabilities of two aspects of the Night Sight Meter scores are shown in Table 1. These reliabilities have been established fairly well by Allgaier (1). The greatest remaining problem has to do with the validity of the instrument, or whether it measures what it is supposed to measure.

Here a number of difficulties arise. If one attempts to use any outdoor criterion such as a person walking, a standing target, car or other object, he is confronted with a number of complications. (1) Different kinds of clothing are worn by the various individuals used as subjects. (2) The presence of buttons and other objects on clothing might reflect light. (3) The face and hands will possibly show up to give cues. (4) Keeping illumination levels constant from period to period during the investigation is a problem. Very few nights of the year have an even distribution of light which remains constant. Any variations in the weather, such as storm, rain, mist, or low visibility due to fog, intense cloudiness, moonlight, etc., tend to invalidate observations and render them noncomparable.

In approaching the problem of testing validity, it became clear that laboratory tests would probably do the job better. At the Driving Research Laboratory at Iowa State College, the Scotometer was developed by Stalder, Hoppe, and Lauer (8). It had been used for the purposes of establishing the lower visibility thresholds for certain types of materials on stationary as well as moving objects. It seemed ideally suited for the purpose of establishing a criterion of visibility against which the validity of the Night Sight Meter could be checked.

More valid results could probably be obtained with 39 subjects on a very highly controlled illumination device of this type than with a larger number of subjects using a less reliable criterion. By actual computation the reliability of the criterion as used here was shown to be .96 or above.

Each subject was given a series of ten observations on each of four types of belts for determining the threshold of visibility. The subject was then measured on the three aspects of the Night Sight Meter in the following order: (a) night vision in low illumination, (b) glare tolerance, and (c) recovery time. Correlations were made between each of these and the criterion.

In addition, 34 other subjects were given the Night Sight Meter tests in order to establish the degree of correlation between the respective measures. This was thought necessary to determine whether all three measures were necessary and which, if any, were similar. Age of the subjects was also included in the matrix of correlations.

APPARATUS

The apparatus used was the Scotometer (8) and the Night Sight Meter which is shown in Figure 1. The subject is placed at the eyepiece with a black hood over the head to secure adaptation to some extent (about three or four minutes) while directions for the experiment are being read. The degree of dark adaptation sought was that which would be found inside the ordinary car or truck cab on the highway at night. This would not be, in any sense, total darkness since headlights extend ahead and there is some light reflected back to the cab. However, it is very low level illumination, probably of the order of 1/50 of a foot-candle, somewhat below the level of average moonlight.

METHOD AND PROCEDURE

The subject is instructed to look into the scope of the Night Sight Meter and fixate a red pilot light of very low intensity. Just to the left of the pilot light is a rotating disc on which are presented broken circles at a constant rate of speed moving past an aperture. The controls on the end of the instrument are shown as indicated by numbers 1, 2, 3, and 4 in Figure 1.

In the present study, the night vision test was given first. This is a different order from that originally proposed by Allgaier (1) in his report on reliability. The reason for reversal in procedure is that the opposing headlights which are turned on by the switch may well carry the person's adaptation level above that to which he was adjusted when the experiment began. It would seem better to have the test for dim light vision given first without the opposing lights. When the switch is turned to the left, the opposing lights are introduced; when turned to the right, these lights go off.

The procedure is to adjust the rheostat, increasing the illumination until the subject can identify properly the broken circles without glare. After one practice trial to emphasize the directions as read to the subject, three additional trials are made, and the mean of the three is recorded as the score for night vision in low illumination without glare.

The procedure was varied slightly for the test of glare tolerance. The subject was asked to read the broken circles against the opposing light, beginning at the 100 mark of the rheostat, which was gradually turned to reduce internal illumination. Otherwise the procedure was identical with that for night vision

TABLE 1

DATA ON NIGHT SIGHT METER

	Scotometer A	Age B	Night Vision C	Glare Tolerance D	Glare Recovery Time E
E	.0219 N = 39	.1778 N = 39	.1988 N = 39 .0392 N = 73	-.0257 N = 39 -.0025 N = 73	not available+
D	.2866 N = 39	.2514 N = 39	.6009 N = 39 .4404 N = 73	.98*	
C	.4266 N = 39	.1788 N = 39	.99*		
B	.0273 N = 39	should be 1.00			
A	.96*				

* Reported by Allgaier

+ Estimated from dates available to be comparable with others

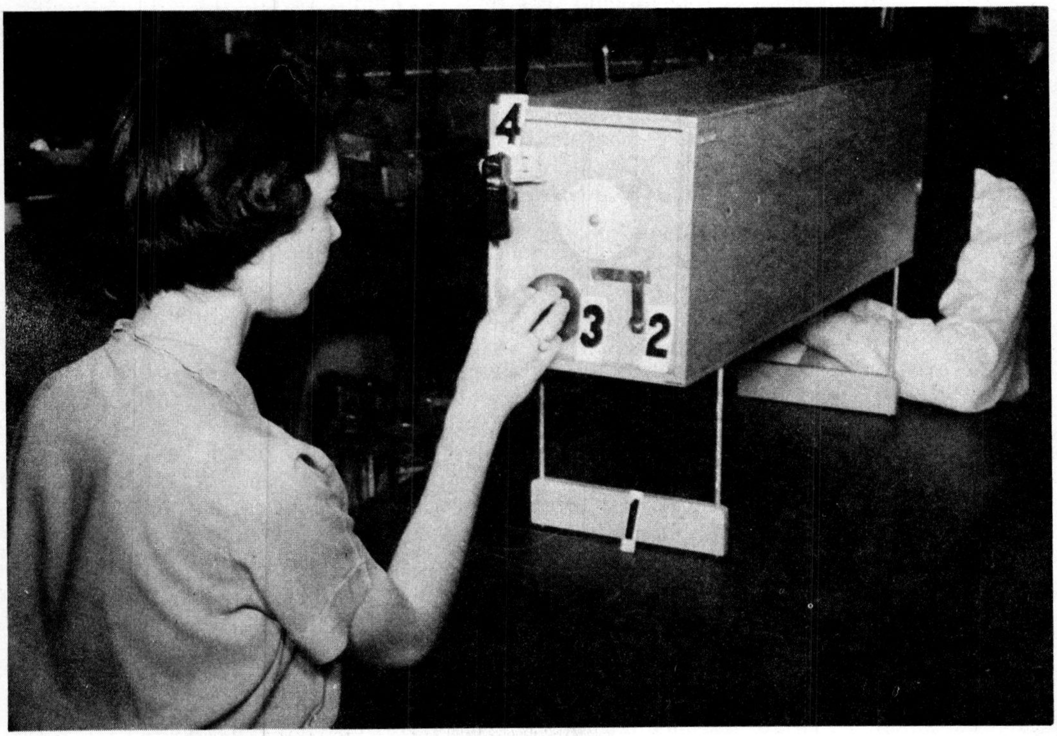

Figure 1. AAA Night Sight Meter. (1) Supports for instrument proper. (2) Switch. (3) Rheostat dial. (4) Pilot light and fixation point source.

except that the glaring lights to the subject's left were shining into the eyes.

The three readings were taken at the point where the breaks in the circles could not be reported correctly, and the mean constituted the score for glare vision. (The experimenter has an accurate check on the broken circles by noting the plate on the outside of the Night Sight Meter.)

A third test consisted of measuring the time required for recovery from glare in terms of seconds to the nearest ½ unit. Here the procedure was varied somewhat for convenience and to shorten the administration time. The dial was arbitrarily set 10 units above that found as the median score in the measurement of night vision in low illumination. The opposing lights were then switched on for ten seconds. At the end of ten seconds the lights were switched off, starting the rotating disc. At the instant the subject could read the broken circles he pressed a button which stopped the revolving dial measuring recovery time in half seconds.

This in essence describes the three procedures used for the Night Sight Meter test to secure scores for night vision, glare tolerance, and recovery time from glare.

RESULTS

As already stated, two groups of subjects were used, 39 of whom were given a carefully controlled criterion test along with the Night Vision Meter and 34 others were given only the Night Vision Meter test. The correlations obtained are given in Table 1 which shows that the measurements of night vision and glare tolerance are quite highly correlated, indicating that the two are fairly highly associated. Both correlate negatively with age. That is to say, the older persons make poorer scores on these two sets of measurements. This is in agreement with the results obtained by Allgaier (1).

However, recovery time does not seem to correlate with either night vision or glare tolerance. This result was not expected since it seemed logical to assume that one who is bothered more by lights would take longer to recover from glare after exposure. This is not the case. The low correlations obtained indicate very little relationship between either of these two measurements and recovery time.

Because of the length of administration time and the relatively high correlation between the night vision and glare tolerance tests, it is suggested that a device be designed which would measure either night vision or glare tolerance and, at the same time, incorporate some feature for measuring glare recovery. In other words, there would be two scores on the revised test rather than three.

To establish a criterion of glare recovery is quite difficult. It would require extensive road tests which would be subject to the same faults in any attempt to secure outdoor tests of visibility as the criterion. So far as recovery time is concerned it will suffice to say that the criterion is self-evident. The fact that one has a long recovery time would in itself be sufficient for the purpose. Professional drivers should have a short recovery time because of the necessity of maintaining night schedules.

The lay driver could be warned of such a condition. This is one of the most valuable aspects of psychophysical testing. Such a clinical approach to the problem of accident prevention seems to be effective, and, when measures which are reliable and valid can be used, eventually some form of them should get into the driver license examination.

It is probably just as important to have one's license marked "restricted to daylight driving" or restricted to slow speeds at night" as it is for having it marked "restricted to driving with glasses." It tends to shift responsibility for safe driving to the person behind the wheel.

SUMMARY AND CONCLUSIONS

In summary, in this study a reliable criterion of night visibility was first established by the use of the Scotometer using 39 subjects. After this the Night Sight Meter was used on 34 additional subjects to establish correlations and the validity of the instrument. The validity is of the order of .40 so far as night vision and glare tolerance in low illumination are concerned. The validity of glare recovery time was very low indicating need for further research in this area. All three tend to deteriorate with age.

It may be said that the validity of the Night Sight Meter is sufficient to warrant its use as a diagnostic instrument, but that the administration time should be reduced. It is suggested that either the night vision or the glare tolerance feature of measurement be omitted and that the glare recovery feature be used in connection with one of the former two. This would reduce the time for administration appreciably.

ACKNOWLEDGMENT

The study reported here was made possible through a grant from the American Automobile Association to the Driving Research Laboratory at Iowa State College.

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Sign Brightness in Relation to Position, Distance, and Reflectorization

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There is need for quantitative comparison of the brightnesses of different sign materials in various situations on the highway. This paper describes a method for calculating the brightness of a reflective material, for a given distance and placement. The method is applied to investigate the effects of such factors as sign position with respect to the pavement, type of reflective material, type of headlamp, type of vehicle, and vertical and horizontal curves. Relationships of these factors to sign legibility and their implications for signing practice are discussed.

● FOR many years one of the principal means of communication between the highway engineer and the motorist has been the highway sign. Recently, with increased demands of traffic, highway signs have assumed a new importance, because they provide the best means of controlling operating speeds and directing traffic through the complicated interchanges that characterize modern highway systems. The message delivered by a sign, important enough during the daytime, becomes even more important at night when visibility is limited.

Only ten or fifteen years ago signs were difficult to read at night, but many of today's signs can be read almost as well after dark as in the daytime. The reflectorized sign has made a great contribution to the development of safe high-speed motor transportation. Today the purchaser of sign material can choose between several different types of reflectorized materials, which differ greatly not only in their cost but also in their brightness in given situations. Sometimes for the signing agency the availability of so many different types of materials can be a mixed blessing.

The Problem

Different demands are placed on a reflective sign material, depending upon the circumstances in which it is to be used. Obviously, the demands on a reflective material are quite different for an overhead sign on a high-speed expressway than for a confirmatory route marker on a country road. In choosing a reflective material for a given application, the engineer must rely on his experience and the advice of manufacturers. Sales representatives from different firms often give conflicting recommendations, and the factors affecting the engineer's choice are so complex that experience is difficult to apply. Wide differences in opinion are encountered regarding the suitability of a particular material for a particular application, and new materials, or recent modifications of old ones, are continually entering the market to confuse the engineer attempting to make a decision.

There is need for quantitative description of the performance of reflective materials on the highway. In addition to permitting a more intelligent choice between sign materials and more intelligent use of them after purchase, such a quantitative description would be a step toward quantitative design criteria applicable to signs for new situations. Van Lear (9) and Finch (2) have outlined procedures for photometric measurement of the reflective characteristics of materials. However, such measurements are of limited usefulness until they have been related to the conditions under which the sign is used on the highway.

The problem of the brightness of reflective materials might be stated as two questions: (a) "How bright should a sign be?" and (b) "How bright is a sign of a certain material in a given highway situation?" In regard to the first question, the basic relationships between brightness and legibility have been discussed in a previous paper (1). The present paper concerns itself primarily with the second question.

Purpose of Study

The purposes of this study were to contribute to the theory of brightness of highway signs in place by using certain photometric techniques, and to apply the theory to representative sign materials in representative highway situations.

METHOD

To determine the brightness, or luminance, of a sign in place on the highway, it is necessary to take into account the reflective characteristics of the sign material; the trigonometric relationships between the car, the sign, and the roadway; and the illumination reaching the sign from the headlamps.

Reflective Materials

The basic principles involved in a study of reflectorized materials (reflex reflectors or retrodirective reflectors) have been explained by Van Lear (9) and Finch (3). The reader is referred to these sources for a complete discussion. In addition, a brief explanation is given here of the principles touched on in this paper.

When light reaches a sign coated with ordinary pigmented paint, it is reflected more or less diffusely in all directions. Very little of the light is returned to the driver's eyes, and such a sign is difficult to read at night. The distinguishing feature of a reflectorized sign is that it concentrates a large proportion of the light into a beam which is directed back toward the source of the light. Since the reflectorized sign appears brighter to the driver, it can be read more easily at night.

Figure 1 shows how a reflectorized sign works. Part A shows the sign being illuminated by a headlamp beam. Some of the light from the source spreads out, goes past the sign, and is lost. Part B shows the sign reflecting light. Much of the reflectorized light is returned in a fairly narrow beam toward the source, but some is spread out in the return beam. The drawing is presented in two parts for simplicity, although illumination and reflection actually occur at the same time. To the person viewing the sign,

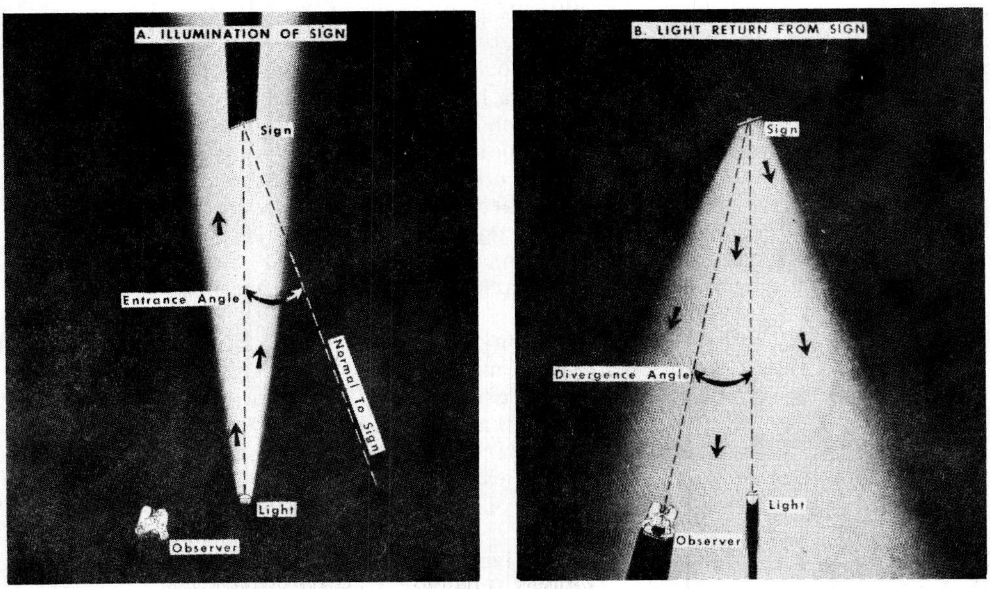

Figure 1. How a reflectorized sign works. Much of the light reaching the sign from the source is returned by the sign back toward the source.

it would appear brightest if his eyes could coincide with the line of the headlamp. As the eyes are moved farther away from the alignment of the light source, the sign appears less bright. The light-sign-eye angle is called the divergence angle. Figure 2 shows the distribution of light in the return beam from one type of sign material. The brightness of the sign is at the maximum when the divergence angle is zero, and it falls off as the eyes move away in any direction from the line of the light source.

Notice the entrance angle in Figure 1. Signs made of most reflectorized materials are brightest when facing the light squarely; that is, when the entrance angle is zero. As the sign is rotated so that the entrance angle increases, the brightness of the sign decreases. The dashed curve in Figure 2 shows the distribution of light in the return beam at a larger entrance angle.

"Luminance," often used to describe the measurement of the brightness of a sign, differs from "brightness" in that it has a specific meaning in terms of the physical measurement of light, whereas "brightness" is a more general term describing appearance to an observer (10).

Both the brightness and the luminance of a sign also depend on how much light it receives from the headlamp. The more light the sign receives from the headlamp, the more it will return to the eye. Figure 2 shows the luminance (in foot-Lamberts) when the sign receives 1 ft C of illumination. If the light received by the sign were 2 ft C, its luminance would be twice as much, and so on. The luminance of the sign when it received 1 ft C of illumination is termed "specific luminance," the unit of measurement used in this paper to describe the reflective characteristics of a material.

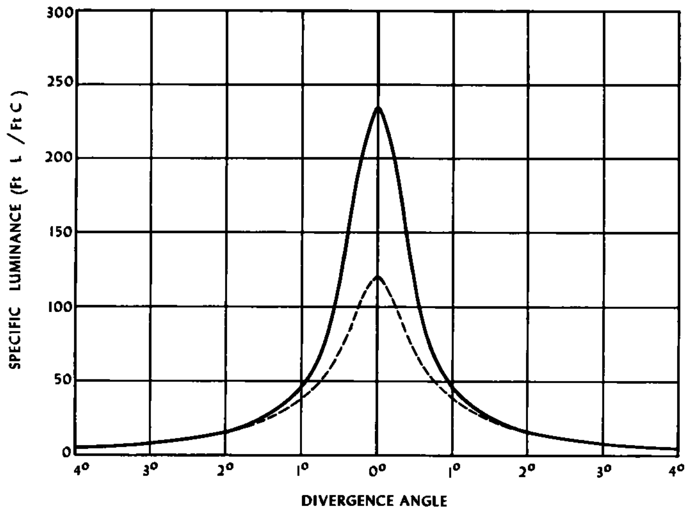

Figure 2. Light return from a reflectorized material. The solid line is for an entrance angle of 0 degrees, the dashed line for 30 degrees.

In plotting curves it is convenient to show luminance and specific luminance on a logarithmic scale. Equal units on a log scale of luminance appear as equal units of brightness to the eye (Fechner's law); perceptible differences in brightness are constant intervals on a log scale of luminance (Weber's law). The log scale was also found more meaningful for expressing relationships involving legibility (1). Figure 3 shows the data of Figure 2 plotted on a log scale of specific luminance. Since the curves for most reflective materials are symmetrical, the left half of the curve can be omitted. In the following section, curves of this type are shown for each type of material studied. Technical descriptions of the units of measurement and the method of measurement are given in Appendix A.

Trigonometric Relationships

To determine the light return from a sign in place on the highway, it is necessary to know the reflective characteristics of the material, which are a function of the entrance angle of the light reaching the sign from the car's headlamp, and the divergence angle between the headlamp and the driver's eyes. Calculation of these angles is not as simple as for the two-dimensional sketch (Fig. 1). Because the sign, the headlamps, and the driver's eyes are not at the same level, the problem must be solved in three dimensions instead of two. Figure 4 illustrates the divergence angle between the driver's eyes and each of his headlamps. It can be seen that the angles are different for each headlamp and that each angle is measured in a different inclined plane. For any given sign position, each of these angles will change continuously as the car approaches the sign.

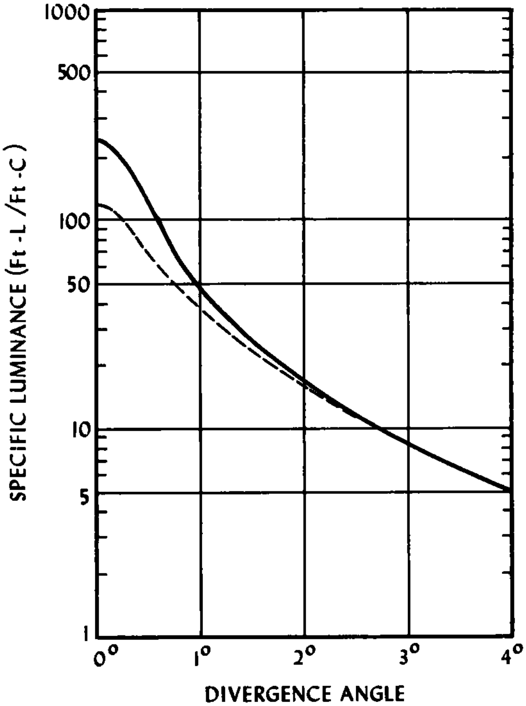

Figure 3. Data of Figure 2 plotted to a semi-log scale. Since the curves are symmetrical, left half is omitted.

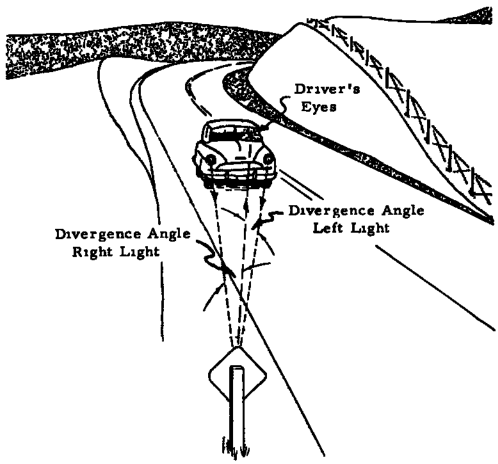

Figure 4. Divergence angles for right and left headlamps of a car approaching a sign.

Solutions were worked out for these angles for any sign position at any distance. Details of the solutions are given in Appendix B. To compute the angles, the dimensions of the car were necessary and measurements of typical late-model cars were made. The average values used in computations are shown in Figure B-1 in Appendix B.

Illumination from Headlamps

To compute the amount of light reaching the sign from the headlamp, it is necessary to know the distance to the sign, the distribution and intensity of light in the headlamp beam, and the position of the sign in the headlamp beam.

For the distribution of light in the headlamp beam, isocandle charts were obtained from headlamp manufacturers. One of these charts is reproduced (Fig. C-1) in Appendix C. It shows the intensity of light at any point in the headlamp beam. The method of determining the position of the sign in the headlamp beam also is explained in Appendix B. For any position in the headlamp beam, the intensity in candlepower can be read from the isocandle charts. The illumination reaching the sign (in foot-candles) is equal to the intensity in effective candlepower (as determined from an isocandle chart) divided by the square of the distance to the sign in feet.

Estimates of the illumination are no better than the degree to which these isocandle charts represent the distribution of light from the headlamps of cars. The isocandle charts used in computations were plotted from a typical headlamp. Although individual headlamps vary somewhat from one to another, the variations in voltages and headlamp aiming are more important. Roper (7) suggests that variations in voltage may introduce as much as 20 percent error in estimates of light output. He also suggests that variations in aiming are often as much as ½ degree, which could double or reduce to one-half the illumination of a point. As shown later, such variations are not as serious as they sound initially, because their effects are small when compared to the 20,000-to-1 range of sign brightness found on the highway. Nonetheless, these sources of error should be kept in mind when interpreting results.

Initial calculations of illumination were made from data for the sealed-beam lamps (No. 4030) produced as standard equipment until 1954. In a later section the effects of the new (No. 5040) headlamps, which have become standard equipment on cars produced since 1955, are discussed.

REFLECTIVE MATERIALS

Five types of reflective materials were chosen for study. These materials are now used in most reflectorized signs, except those using reflector buttons (which are not directly comparable to continuous-surface materials). Although letters made from buttons appear continuous to the eye when the sign is read at a distance, the relationships between the legibility and photometrics of buttons are essentially different from those of continuous-surface materials. Therefore, it would be misleading to include curves for reflector buttons with those of the continuous-surface materials. The method employed in this report can be used to compute the intensity of light of a reflector button in a manner comparable to the calculation of the luminance of continuous-surface materials (intensity in apparent candlepower is equal to illumination times specific intensity); however, no research to date has established the relationship between the legibility of reflector-button letters with a given intensity and that of continuous-surface letters (or background) of a given luminance. Until such research is done, it will not be possible to make a valid comparison of the two. Therefore, the present study confined itself to reflective materials with surfaces of uniform brightness. Each type of material was studied under a microscope. Figures 5 through 9 are photomicrographs of the five types and diagrams showing them in cross-section.

Beads on Paint

The least expensive type of material (Fig. 5) is built up directly on the aluminum or steel sign backing, and can be made in highway department sign shops. After the metal has been given a primer and an undercoat of paint, a special binder paint is applied. While the film of binder is still wet, a layer of tiny round glass beads is deposited on it. The beads are held in position by the paint. Figure 5 shows how this material works: a ray of light enters the bead and is reflected in the direction from which it came.

These beads are so small (about 0.004-in. diameter) that about 20 million are required to cover the surface of an average sign. Accurate control of paint film thickness and of the application of beads is required for a good-quality product. If the beads are not embedded firmly, they spall off in use and the sign will have poor durability. If they are embedded too deeply, paint will cover part of the bead surface (or even cover some beads completely), causing poor reflective performance. Signs made of this material range in quality from very good to very poor, depending upon the equipment used and the care and skill which goes into production of the material.

Beaded Sheeting

Except for its higher quality and higher cost, the beaded sheeting type (Fig. 6) is essentially like beads on paint. In mass production it is possible to achieve uniformly good control of the placement of beads in the binder. Although the beads are smaller than grains of salt, the microscope shows each bead to be firmly embedded in the binder, yet each bead has almost exactly one-half its surface exposed to reflect light. This material is supplied in rolls of sheeting, which are usually cut to size and applied to the user's sign blanks with an adhesive activated by heat or a special solvent.

Flat Sheeting

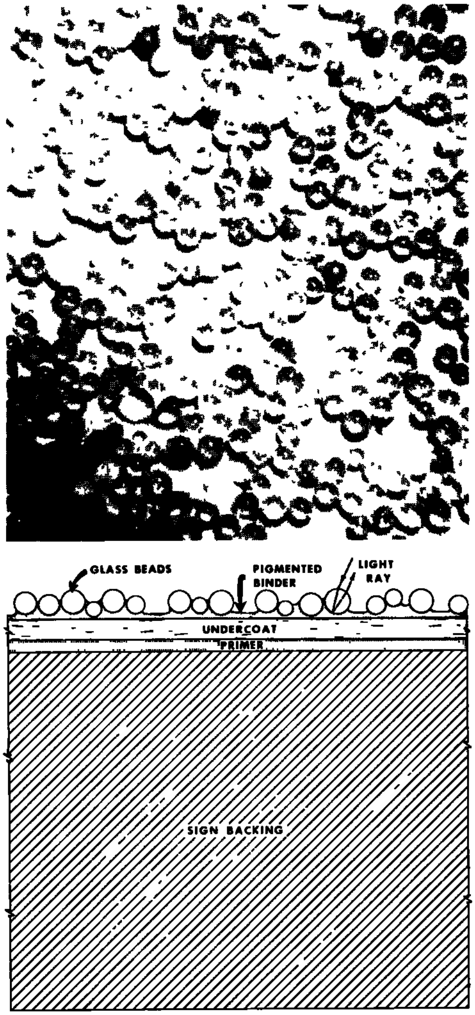

Figure 5. Photomicrograph and cross-section sketch of beads-on-paint type material (30 times actual size).

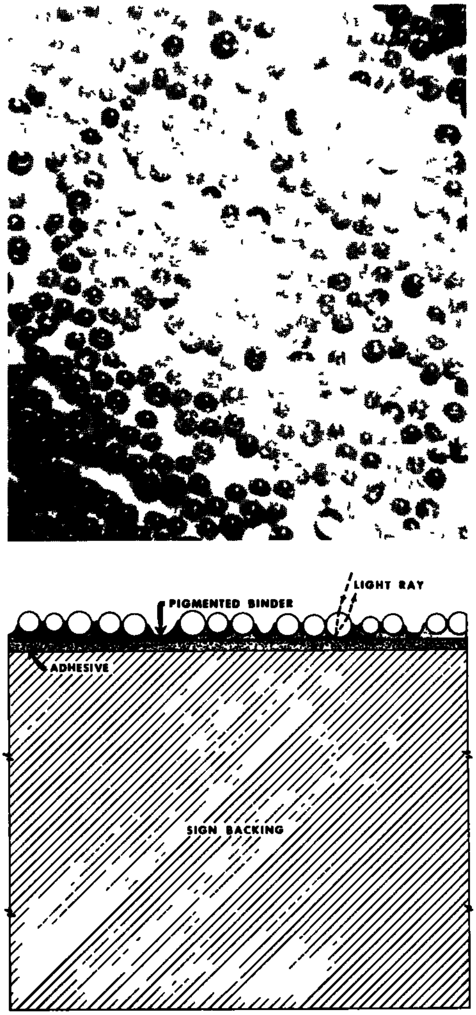

Figure 6. Photomicrograph and cross-section sketch of beaded sheeting type material (30 times actual size).

Flat sheeting (Fig. 7) is more complex and more efficient as a reflector, but more expensive than the two materials previously described. Smaller beads, with a higher index of refraction, are embedded in a low-index plastic and covered by a flat plastic surface. Behind the beads and their plastic matrix is a metal film reflector. Figure 7 shows a ray of light brought to focus on the metal film and returned in the direction from which it came. Flat sheeting is applied to the sign blank in the same manner as beaded sheeting.

Thin Lens-Mirror

The thin lens-mirror (Fig. 8) uses a different optical principle from the materials already described. Instead of gaining its reflective qualities from glass beads, it makes use of tiny lenses molded on the surface of a sheet of plastic. These lens focus the incoming light on the mirror-like back surface so that the light is reflected back toward its source. In cost and reflective efficiency, this type is comparable to flat sheeting. It usually is furnished in sheets to be applied to the user's sign blanks with an adhesive, although a new product furnished in rolls of sheeting has recently been made available.

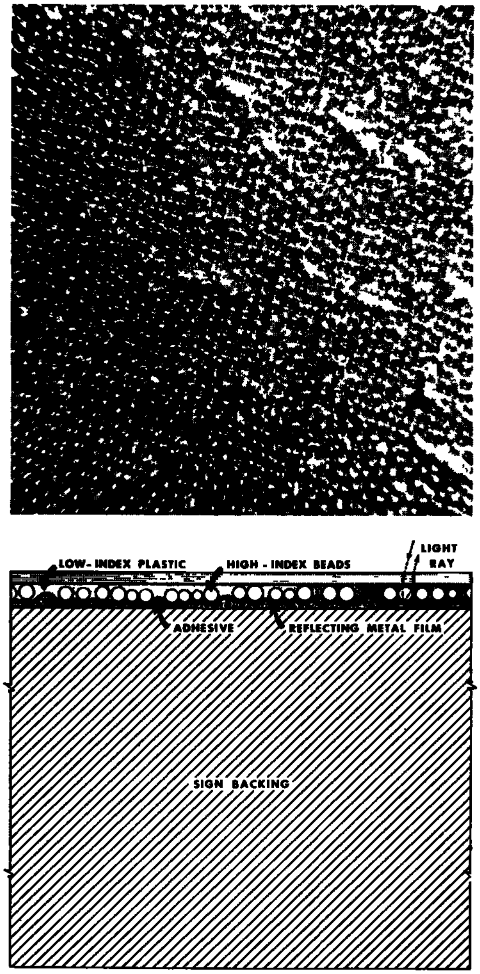

Figure 7. Photomicrograph and cross-section sketch of flat sheeting type material (30 times actual size).

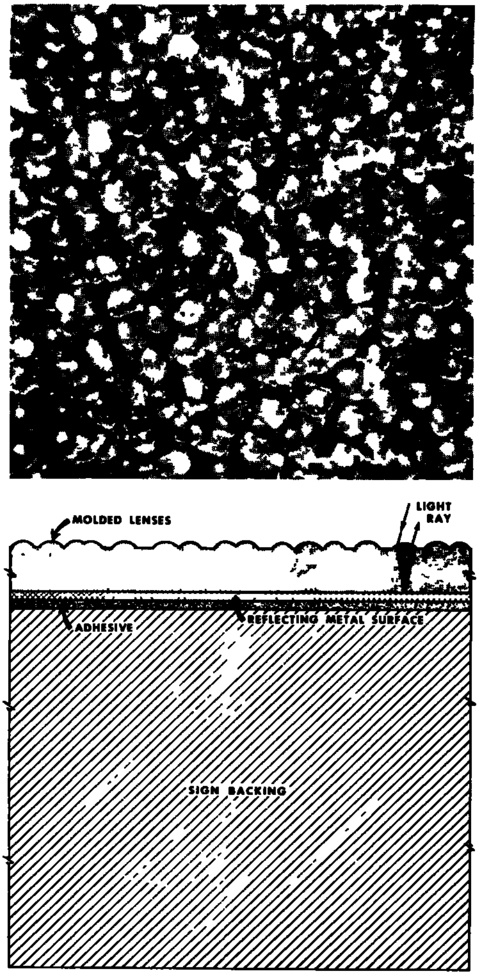

Figure 8. Photomicrograph and cross-section sketch of thin lens-mirror type material (30 times actual size).

Thick Lens-Mirror

The thick lens-mirror (Fig. 9) is similar to the preceding material except that the lenses are much larger and the plastic sheet is correspondingly thicker. It is commonly purchased in the form of cut-out letters or symbols, which are screwed or bolted to the face of the sign. The perfection with which these lenses are molded can be appreciated only when it is realized that each lens is about the size of the dot over an "i" on this page. Such perfection gives a very high reflective efficiency. This material is the most expensive of the types described.

Reflective Characteristics

In the laboratory, photometric measurements were made of specimens of each type of material using the method described in Appendix A. The results are shown in Figure 10, which shows the values of measurements on white or silver samples; curves for other colors would be essentially parallel. It should be emphasized that these measurements were made on only one or a few samples of each material and do not necessarily represent exactly the photometric characteristics of specific products available

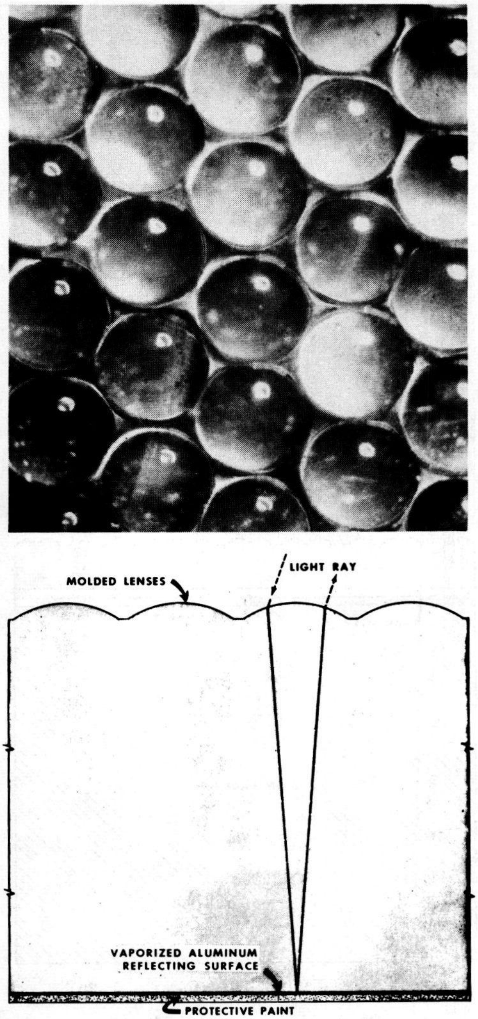

Figure 9. Photomicrograph and cross-section sketch of thick lens-mirror type material (30 times actual size).

on the market. Also, the measurements were made on new clean samples and do not take into account effects of age, dirt accumulation, or weather conditions. However, the range of photometric characteristics shown is representative of those found in different materials available today and constitutes a sound basis for study. This investigation was not intended to compare specific materials either favorably or unfavorably. Instead, an attempt was made to understand the characteristics of different types of continuous-surface material in their relationship to highway sign uses. A simple comparison of materials is invalidated as soon as the properties of one material change; instead of seeking information about a particular product, the reader is encouraged to think in terms of the basic relationships involved. A set of curves (Fig. 10) is shown for each of the materials described, with one curve for each entrance angle. Only one curve is shown for beads on paint, since the specific luminance of this type of material is almost the same at all entrance angles. The reflective properties of this type of material are quite variable, depending on the quality of workmanship, but the curve shown is judged to be the average to be expected from beads-on-paint signs produced in a highway department sign shop. (Since the data in Figure 10 were secured, significant modification has been made in beads-on-paint type material. A recent manufacturer's sample, apparently using higher index beads, produced a peak specific luminance almost twice as high as that shown.) The properties of the three materials shown on the left in Figure 10 are little affected by entrance angles commonly encountered on the highway. The properties of the lens-mirror types, however, are more affected by entrance angle, so the data are shown separately. It should be noted that a recent sample of thin lens-mirror material, slightly different in construction from samples previously secured, produced specific luminance values significantly higher than those shown in Figure 10.

In the past, curves of this type (in terms of specific intensity per square inch) have been used as a basis for specifications; however, until they are quantitatively related to the highway situation these curves have limited meaning.

RESULTS FOR A STRAIGHT LEVEL ROAD

The luminance or brightness of each material was calculated for distances from 40 to 2,000 ft, for typical sign positions on a straight level road, and for upper and lower headlamp beams. Because of space limitations it was not feasible to include the curves for all possible combinations of materials, headlamp beam, and sign position. A typical material is used to show the effect of sign position, and a typical position is chosen to show the effect of sign material. In the later section on vertical and horizontal curves,

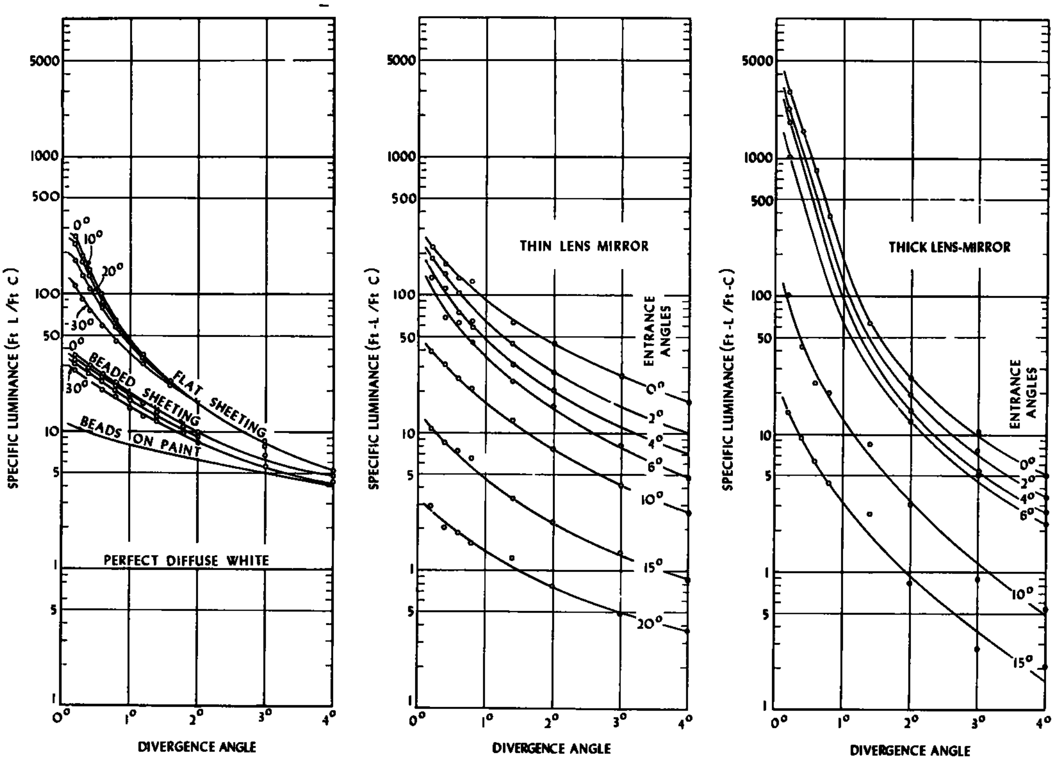

Figure 10. Laboratory photometric data for the five types of reflective materials studied in this paper.

the typical material and the typical sign position are used to show the effects of curvature. In each case where a type of material or a position other than the typical yielded different results, the fact is noted and discussed.

Because of the differences in the illumination provided by the left and right headlamps (see Appendix C) as well as in the trigonometric relationships for right and left headlamps (see Appendix B), it was necessary to make calculations for each headlamp separately. Figure C-3 shows the luminance of each headlamp separately; however, the total luminance seen by the driver is the sum of the luminances for the two headlamps. Therefore, all results shown in the text are based on the total luminance from both headlamps.

Assumptions

Calculations of luminance were based on the following assumptions:

1. All signs were considered to be mounted plumb and perpendicular to the roadway.
2. The car was positioned on the highway so that its right headlamp was 2 ft horizontally from the edge of the pavement.
3. The dimensions of the car were those of an average late-model car referred to earlier and shown in Appendix B, Figure B-1.
4. The car was equipped with standard GE No. 4030 headlamps in good condition with proper alignment and voltage.
5. Each type of sign material was new, clean, and dry, white or silver in color, and had photometric characteristics like the samples measured in the laboratory.

Sign Position

The position of the sign with respect to the pavement has an important bearing on its luminance to the driver. Six sign positions, covering the range of positions specified

TABLE 1

SIGN POSITIONS INVESTIGATED

Sign Position	Feet Above Pavement	Feet Over From Edge of Pavement	Common Application
1	5	6	Rural
2	5	10	Rural
3	8	2	Urban
4	8	6	Rural or Urban
5	8	10	Rural or Urban
6	16	-	Overhead

by the Manual on Uniform Traffic Control Devices (11), were chosen for investigation. These sign positions are shown in Table 1. Signs in any one of the six positions are likely to be encountered on rural highways. Position 3 is the most common in urban areas, although in such areas there is often another lane of traffic or a space for parked cars, so that sign positions 4 and 5 are, in fact, common in urban as well as rural areas. The overhead sign, position 6, is being used more frequently in both rural and urban areas.

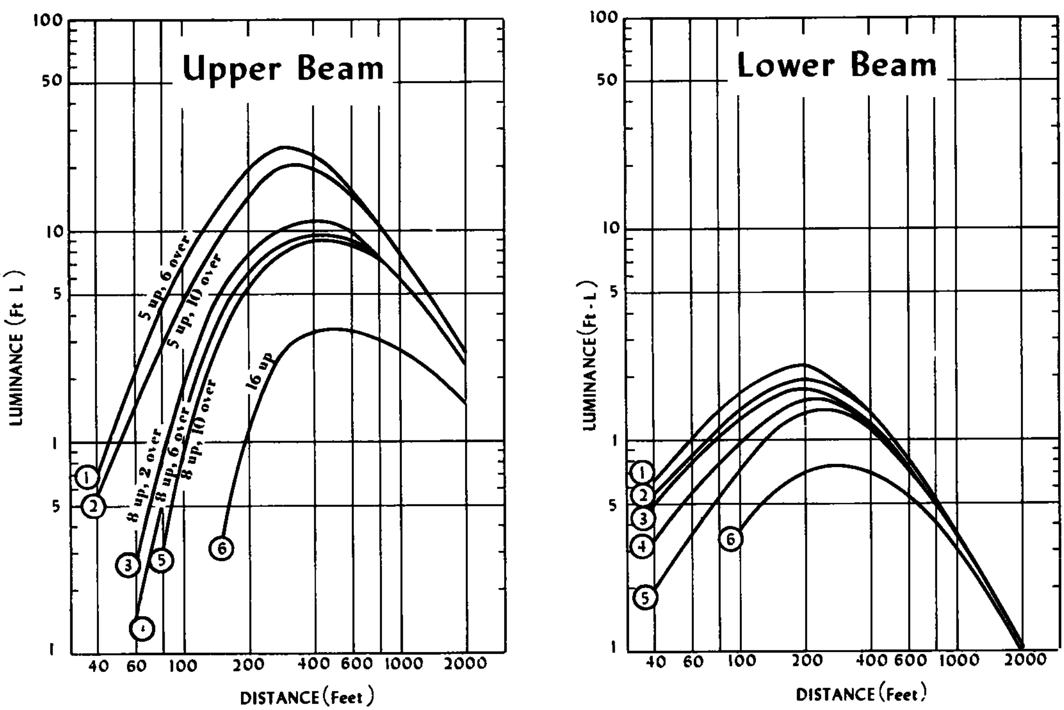

Figure 11. Effect of sign positions (see Table 1) on luminance for flat sheeting type material illuminated by a car equipped with No. 4030 headlamps approaching a sign on a straight level road.

Figure 11 shows the relationship between sign luminance and distance for various sign positions on a straight level road for flat sheeting. The shape of the curves is characteristic of most of the results. The luminance is relatively low at short distances, where divergence angles are large and the sign is out of the intense portion of the headlamp beam. The maximum luminance is reached at an intermediate distance and falls off gradually. When plotted on logarithmic paper, the luminance-distance relationship approaches a straight line at long distances.

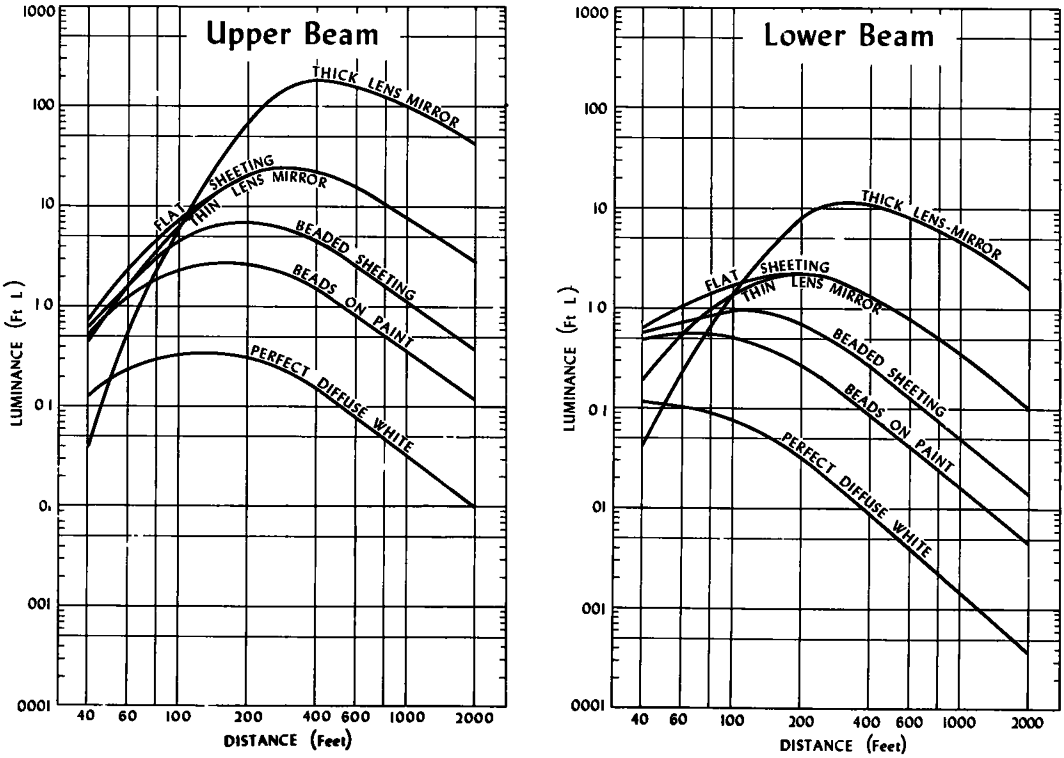

Figure 12. Effect of reflective materials on luminance for sign position No. 1 on a straight level road with illumination from No. 4030 headlamps.

Several characteristics of the curves should be noted. The curves show that height of signs has more effect on luminance than lateral distance from the pavement. The curves for signs placed 5 ft and 8 ft above the pavement are in distinct groups, with lateral distance having a significant effect only at quite short distances. The main variable causing this effect is the broad, flat shape of the headlamp beam. The overhead sign (position 6) yields a curve separate from the other two heights. The importance of overhead signs, which are placed at high-volume high-speed locations, coupled with the fact that the luminance of overhead signs is less than that of roadside signs, presents a problem worthy of special notice.

Headlamp Beams

In general, at short distances (roughly 200 ft) the luminance values for upper beams are about 10 times those for lower beams. At long distances, upper beams give 15 to 25 times the luminance for lower beams.

Reflective Materials

The luminances of the five types of reflective material, for sign position 1 (5 ft up and 6 ft from the edge of the pavement) are shown in Figure 12. The lowest curve, which shows the luminance of a perfect diffuser (a perfectly flat white paint), might be considered as a reference line representing performance of a sign without reflectorization. For all practical purposes it is also the curve for the illumination reaching the sign from both headlamps.

The curves for each material show how the luminance changes with distance to the sign. The curves for flat sheeting and thin lens-mirror were almost the same (for the samples tested) beyond 200 ft and are shown as the same curve beyond that distance. At near distances the luminance of thin lens-mirror is less because this type of material is more sensitive to changes in entrance angle than flat sheeting.

The thick lens-mirror type is very bright at its peak and maintains a high luminance even at 2,000 ft. At near distances, however, its luminance falls off rapidly. It should be noted that this low luminance at near distances is due not only to the entrance angle characteristics of the materials but also to the divergence angle characteristics. Any bright material concentrates its light into a beam of small divergence angle. There is, then, little light return at the large divergence angles encountered at near distances, and the high-brightness materials cannot give their best performance except at greater distances.

In most cases, low luminances at short distances are not important; once the sign becomes legible by virtue of its size as the car approaches, it will remain easily legible until the car is past the sign. However, it may be possible for materials of high brightness (that is, those which concentrate the returned light in a beam of narrow divergence angle) to become unreadable at near distances, especially if they are also sensitive to changes in entrance angle. Examination of the results so far indicates that one of the most important factors governing the choice of reflective material is the distance at which the sign must be read. Consider a sign which can be read with lower headlamp beams at 100 ft with letter size so small that the sign could not be read at far distances no matter what its luminance. Referring to Figure 12, at 100 ft little luminance is gained by use of a more expensive material. At 800 ft, however, flat sheeting or thin lens-mirror is required to give the same luminance as that produced by the cheapest material at 100 ft. At 2,000 ft only the brightest material has a luminance as great as that of the cheapest material at 100 ft. This indicates that for small signs with small lettering the material with the lowest long-range cost may be the best choice, whereas for a very large sign designed to be read at a great distance the most expensive material may be the best and only choice.

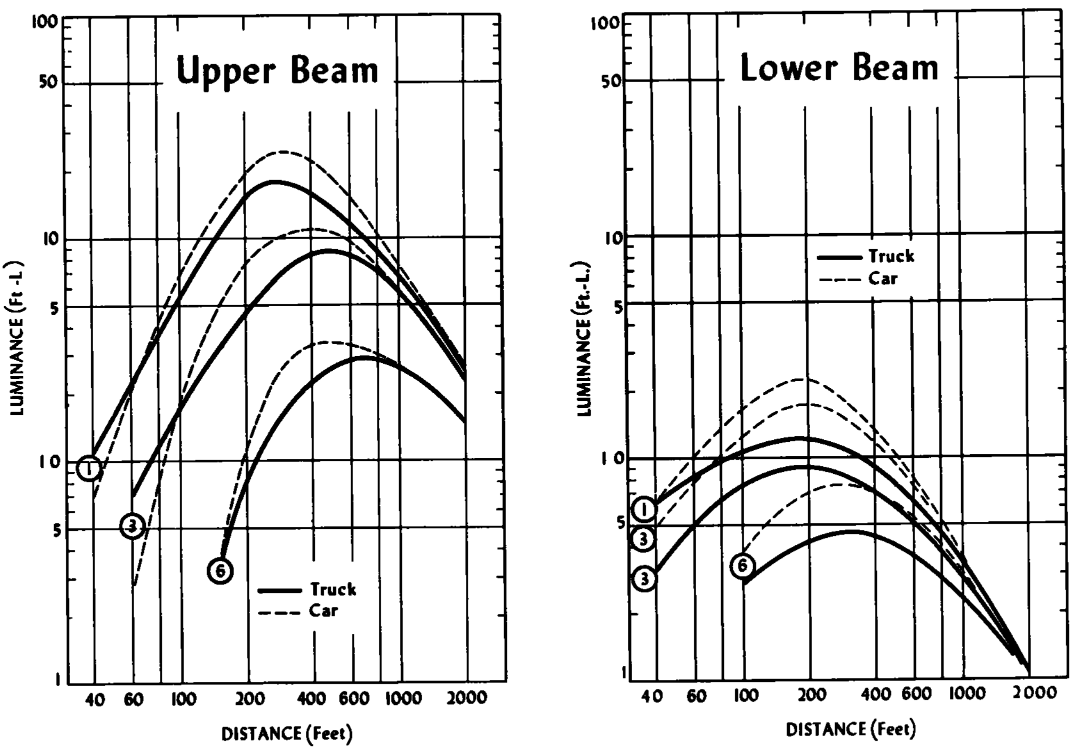

Figure 13. Truck-car comparison vs distance for various sign positions. Dashed lines repeat some data shown in Figure 11.

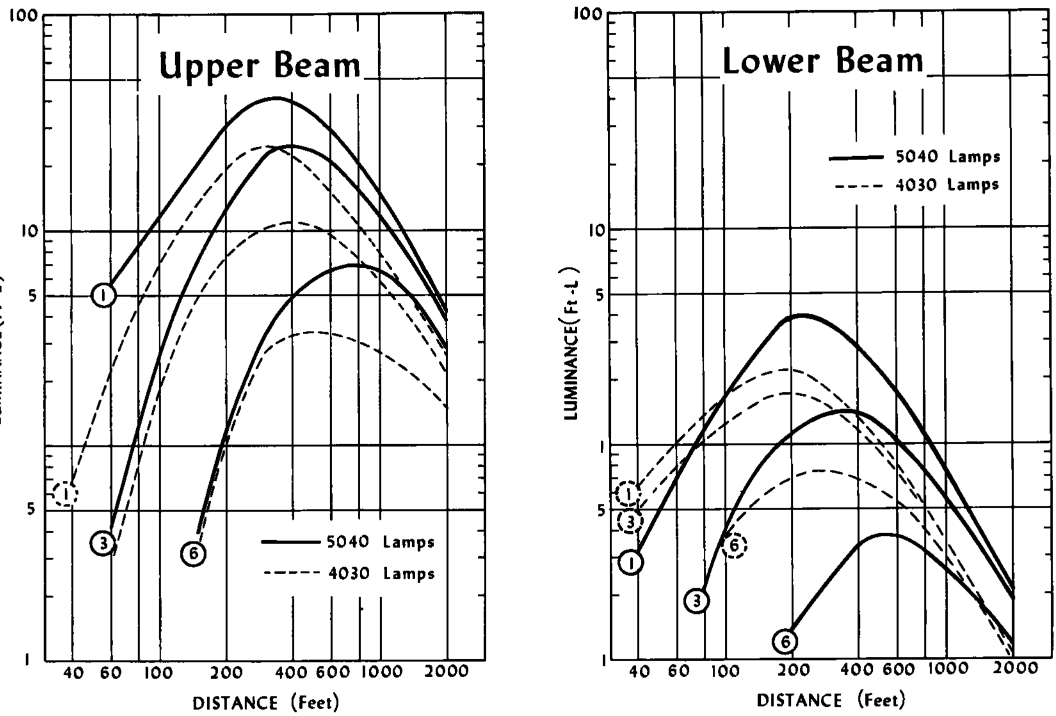

Figure 14. Comparison of luminance of No. 5040 and No. 4030 headlamps for various sign positions. Data shown by dashed lines also shown in Figure 11.

Truck-Car Comparison

Because of the different dimensions of a truck, the luminance of a sign will be somewhat different to the driver of a truck than to the driver of a car. The headlamps of a truck are higher above the pavement than car headlamps, and the driver's eyes are higher above the headlamps. Measurements were made on a sample of large trucks and the average dimensions used in calculations are given in Appendix B, Table 2. A wider variation in dimensions was encountered than in the sample of cars, so the average values used in truck calculations are somewhat less representative than those for the cars.

In Figure 13, the dashed lines are the results previously shown in Figure 11 for the average car and for flat sheeting at three sign positions. The solid lines show results for a large truck. Luminances as seen by the driver of a truck are generally lower, although the differences are not great. The factor accounting for the reduced luminance is the larger divergence angles. Although the illumination reaching the signs was slightly greater, because a truck's headlamps are mounted higher above the pavement, this effect was more than balanced by the increase in divergence angle. The reduction is greater for the brighter materials, since they concentrate the returned light into a beam of smaller divergence angle. However, even for such materials it is doubtful that the effect is of great importance. In general, the luminance of signs to the driver of a large truck will be slightly less, but this difference will be insignificant except for high-brightness materials at near distances.

New Type Headlamps

All previous data in this paper have used illumination values for the old type of sealed-beam headlamp, which was standard equipment on automobiles until 1955. Since 1955, the new No. 5040 lamp (50-w upper beam, 40-w lower beam) has replaced the old type No. 4030 (40-w upper beam, 30-w lower beam). The new headlamps have been

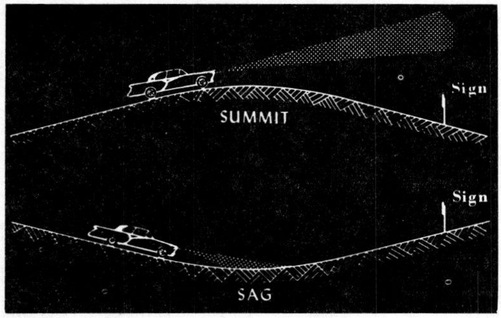

Figure 15. Relationship of main portion of headlamp beam to sign as car passes over vertical curves.

described by Sherman (8). The upper beam of the new lamp differs from the old in having a higher intensity at the center of the beam and a sharper vertical cutoff. Two important changes have been made in the lower beam. With little change in the glare to opposing traffic, the new lower beam gives significantly increased visibility distances on the right-hand edge of the road. Also, addition of a filament cap over the lower-beam filament results in a large reduction in the stray light scattered upwards at near distances, giving considerably better visibility in fog, falling snow, or rain.

The effects of the No. 5040 headlamp on sign luminance were also investigated. The isocandle charts for 6-v No. 5040 lamps were used. Although the 12-v lamps have slightly lower rated candlepower, Roper (7) advises that the overvoltage found in vehicles using the 12-v system yields about the same candlepower distribution as for the 6-v lamps.

The dashed curves in Figure 14 are the data previously shown in Figure 11 for flat sheeting. Differences in luminance produced by the two headlamps would be similar for all other materials. The solid lines show results for the No. 5040 headlamp. The new upper beams give about the same luminance at near distances, but give greater luminance for all sign positions at far distances.

For the new lower beam, there is generally lower luminance at near distances and higher luminances at far distances. The overhead sign, position 6, deserves special attention. Except at far distances, there is a marked reduction in the light reaching an overhead sign from the new lower beam. For overhead signs already having rather low luminances, the problem is compounded by the reduction in light received from the lower beams of the new No. 5040 lamps.

RESULTS FOR VERTICAL AND HORIZONTAL CURVES

The data presented up to this point have been for a straight, level road, but vertical and horizontal curves have marked effects on sign luminance. Although it is possible to compute luminances for any combination of horizontal and vertical curvature, only a minimum of data is included to show the nature of the relationships and the relative magnitude of the effects. As in previous sections, results are shown for one type of material and one sign position, and important differences in relationships for other materials and positions are noted.

Vertical Curves

The most important effect of curvature is its influence on the position of the sign in the headlamp beams. The effect of vertical curves on the illumination reaching the sign is shown in Figure 15. As the car approaches the sign over a summit, the headlamp beams are aimed above the sign; for a sag, the beams of the approaching car are always aimed below the sign.

To arrive at a solution to the problem, some assumptions about length and symmetry of the curve, difference in grade, and sign position had to be made. Symmetrical curves 1,000 ft long were assumed, with algebraic differences in grade from 0 to 10 percent. This range of vertical curves is representative of those encountered on high-type major highways, but much more pronounced curves are found on secondary highways. Calculation of entrance and divergence angles and the position of the sign in the headlamp beam is somewhat more complicated than for a straight level road. The method is described in Appendix B. As before, the sign is assumed to be mounted plumb and perpendicular to the roadway.

Figure 16 shows the luminance of flat sheeting in the assumed sign position (5 ft up

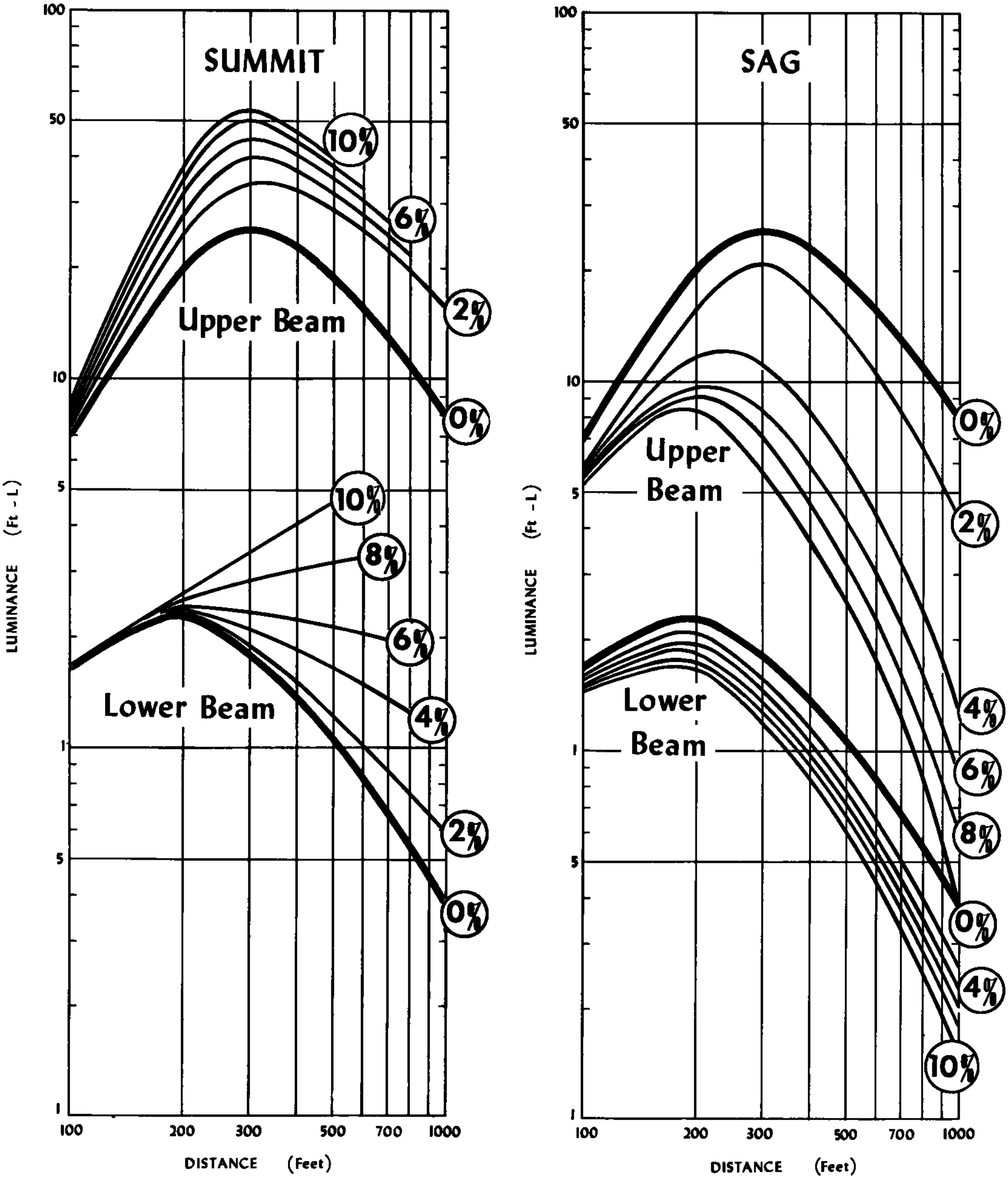

Figure 16. Luminance vs distance for various vertical curves. Bold lines show same data as in Figure 11 for sign position 1.

and 6 ft from the edge of the pavement and at the end of a 1,000-ft vertical curve) illuminated by No. 4030 headlamps. The heavy lines labeled 0 percent represent the data previously presented for a straight level road for position 1, and each of the other curves is labeled with the algebraic difference in grade. Since differences in luminance at near distances are small, only distances beyond 100 ft are shown. Each curve for a summit is cut off where the sign is shielded from the headlight beam by the crest of the hill.

Under the conditions assumed, luminances for a summit are always greater than for a level road, because the headlamp beam is aimed more directly at the sign. If a

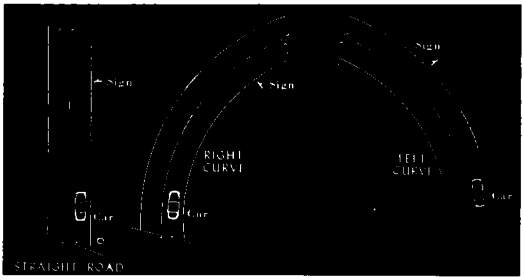

Figure 17. Relationship of main portion of right headlight beam with respect to sign as car proceeds around horizontal curves.

sign tends to be so bright on a level road that legibility is decreased (1) the problem would be accentuated on such a vertical curve. Conversely, luminances are always less for a sag. In certain applications on vertical curves, this reduction in luminance has a great effect on the distance at which a sign can be read. For example, an overhead sign would be still farther outside the intense portion of the headlamp beam, and would have still lower luminance than a roadside sign. The situation becomes more unfavorable when the lower beam of the No. 5040 headlamp is used. The resulting low luminance of any available reflective material suggests that artificial illumination may be necessary for overhead signs located beyond sags.

Luminance curves similar to Figure 16 for other types of sign material closely parallel those shown for flat sheeting. The characteristics of the material were not affected differently because vertical curves do not cause significant changes of entrance and divergence angles.

Horizontal Curves

The effect of horizontal curvature on the position of the sign in the headlamp beam is shown in Figure 17. A sign on the right shoulder of a right curve is always to one side of the centers of the headlamp beams. For a left curve, the center of the beam is at first to the right of the sign, but as the car approaches the center of the beam swings by the sign to the left.

The car was assumed to be approaching the sign on a continuous curve. Calculations were made for 0-, 2-, 4-, and 6-degree curves, both right and left. As before, the sign was assumed mounted plumb and perpendicular to the centerline of the roadway. No account was taken of superelevation. Methods of calculation are outlined in Appendix B.

Figure 18 shows the luminance-distance curves for the same material and position previously discussed (flat sheeting 5 ft up and 6 ft from the pavement edge. The curves for a straight level road are shown (0 degrees) as heavy lines for reference. The range of curve chosen (0 to 6 degrees) includes all curves usually found on high-type major highways, but curves considerably sharper are found on secondary highways. A right-of-way of 110 ft is assumed and the 4- and 6-degree curves terminate at the distance where the line of sight is interrupted by the fence line. The line of sight would be interrupted sooner in a cut, but would not be a limiting factor in a fill section.

Figure 18 shows that on right curves luminances are always less than on a straight road, while left curves have a peak luminance at near distances where the headlamps are pointed almost directly at the sign. The loss of luminance is greater for upper beams than for lower beams; although upper beam luminances are reduced to as low as one-tenth of their straight-road values, lower beam luminances do not become less than one-third of their straight-road values.

It should be remembered that these curves were prepared for flat sheeting only, which is not very sensitive to changes in entrance angle. Since divergence angles are not greatly affected by horizontal curvature, the main factor affecting the changes in luminance in Figure 18 is illumination.

Data for types of material other than flat sheeting were also computed. Because of the effects of entrance angle, the plotted results were not parallel to those shown for those types of material sensitive to changes in entrance angle. Therefore, it is necessary to consider the effects of entrance angle characteristics.

EFFECT OF SIGN ROTATION

As previously pointed out, different types of materials differ greatly in how much

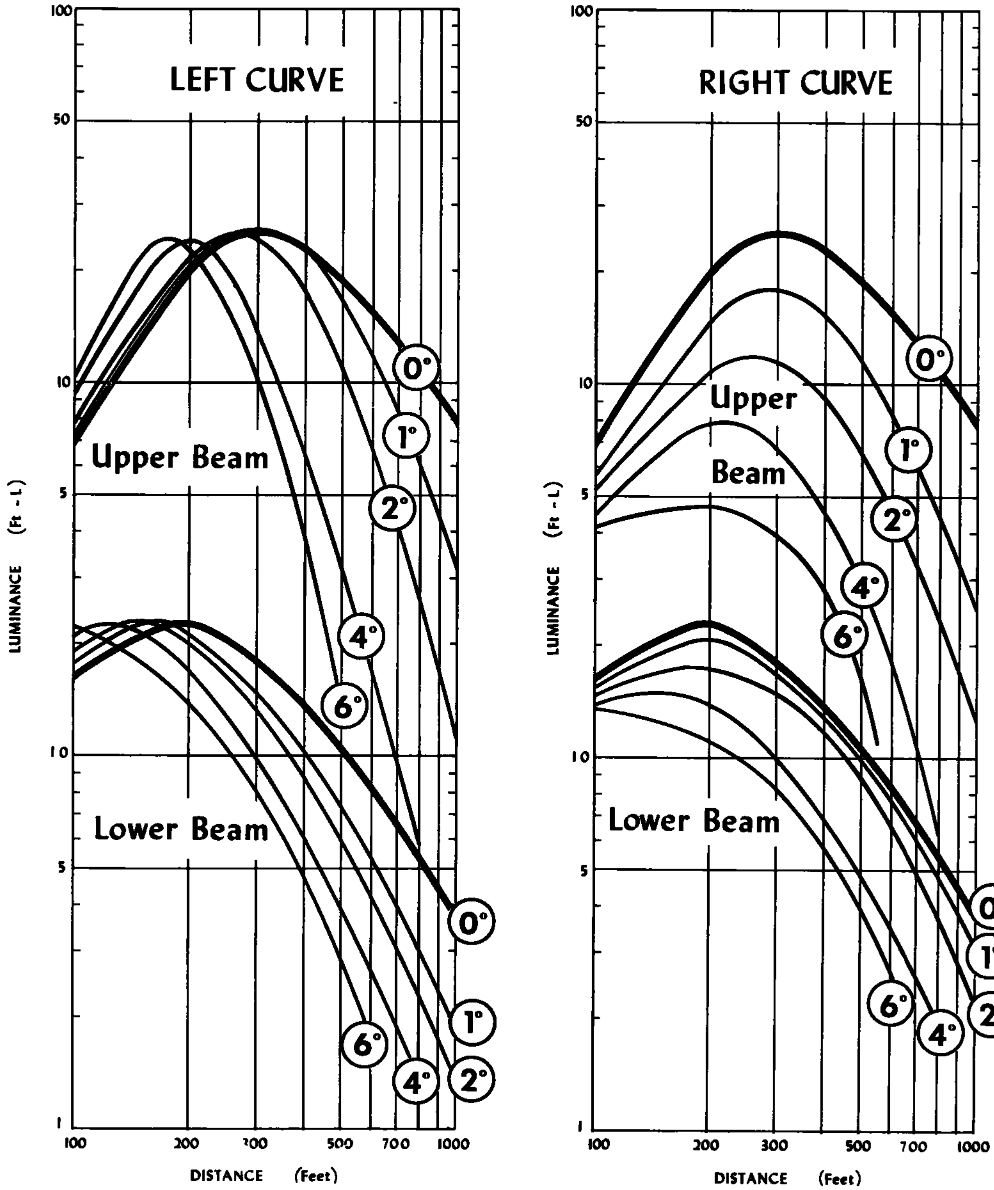

Figure 18. Luminance vs distance for various degrees of horizontal curvature. Bold lines show same data as in Figure 11 for sign position 1.

their brightness is affected by the entrance angle. Of the types included in this study, only the lens-mirror types were very sensitive to changes in entrance angle. In the following discussion, only the thin lens-mirror type is considered, since its brightness is roughly the same as the "typical" material, flat sheeting, except for its entrance angle characteristics.

When a sign is erected it can be rotated, within certain limits, to any desired angle with respect to the roadway. When painted signs were used, it was common practice to rotate them away from the road about five degrees to avoid specular reflection. This is still desirable for materials having high specular reflection, but it is certainly not desirable for materials sensitive to changes in entrance angle.

Rotation on a Straight Road

Figure 19 shows the effect of sign rotation on the luminance of thin lens-mirror type of material on a straight level road. The sign is assumed to be mounted as before, 5 ft above and 6 ft from the right edge of the pavement. The 0-degree curve is for no rotation, (sign face perpendicular to road). The clockwise rotation faces the sign toward the road and counterclockwise rotation faces the sign away from the road.

It can be seen (Fig. 19) that a 5 degree clockwise rotation does not affect luminance very much, but produces a slightly brighter sign at near distances and a slightly less bright sign beyond 250 ft. A 10 degree clockwise rotation brings about a substantial reduction in luminance at all but very near distances. As would be expected, counterclockwise rotation (facing the sign away from the road) causes even greater reductions.

To achieve maximum performance from a material sensitive to changes in entrance angle, care must be used in facing the sign properly when it is erected. To achieve maximum performance of these materials, orientation should be within ± 5 degrees; misaiming by more than 10 degrees will cause a serious loss of brightness. No reliable information is available regarding the ability of sign crews to aim signs with respect to the pavement, but with reasonable care competent workmen should be able to place a sign within 5 degrees of the the correct aiming on a straight road.

Rotation on Curves

As mentioned previously, the entrance angle conditions for both vertical curves and straight level road sections are quite similar; therefore, the problem of rotation on vertical curves is the same as for straight roads. Recognition of the effect of sign rotation on horizontal curves is important, however, in order to minimize the reduction

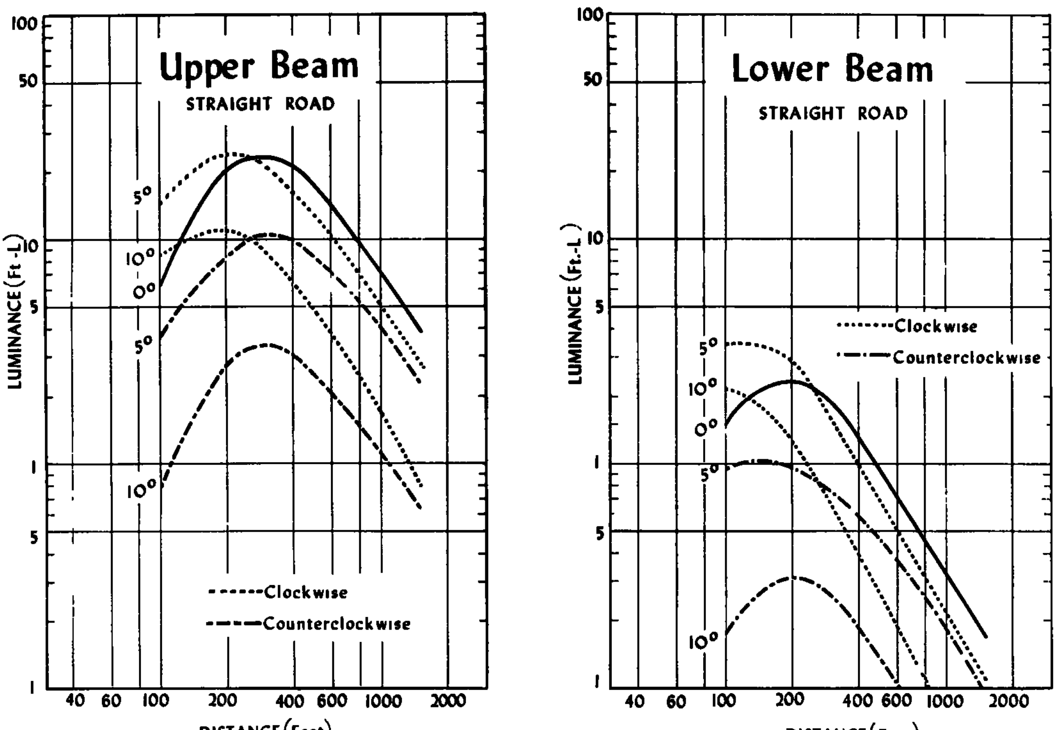

Figure 19. Luminance vs distance for various amounts of rotation of thin lens-mirror material. Roadway alinement is assumed flat and straight and sign is in position 1. Zero-degree curve is based on assumption that sign is mounted perpendicular to roadway.

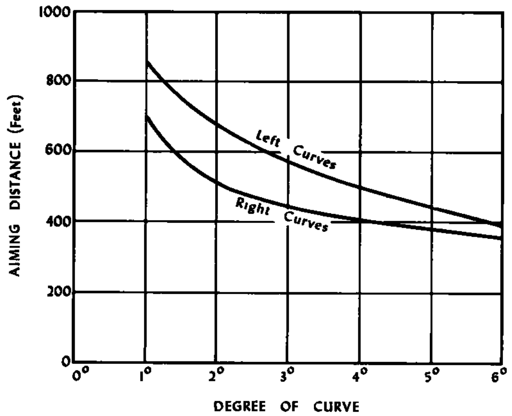

Figure 20. Aiming distance vs degree of horizontal curve for optimum performance of thin lens-mirror material.

of luminance resulting from large entrance angles.

It is possible to compute the luminance at any distance for any degree of rotation; however, the distance at which the sign is to be read is an important factor. Obviously it would be out of the question to orient a sign for luminance to a distance of 1,000 ft when its letter size at any luminance makes it illegible beyond 500 ft. However, it was of interest to see if it were possible to rotate the sign through a certain angle so that the effects of entrance angle characteristics would be small within the range of distance that the sign was visible around the curve. Luminances within this range of distances were plotted for several degrees of rotation, for right and left curves to values of 6 degrees of curve. The effects of entrance angle were found to be more critical for right curves than for left curves (for a sign mounted on the right-hand side of the road). On left curves, aiming the sign toward a point some distance back on the curve results in rotation toward the road, which increases brightness at near distances. For right curves, aiming toward a point some distance back on the curve rotates the sign away from the road. This causes reduced luminance at near distances.

Optimum rotations were estimated for thin lens-mirror material for both right and left curves. Figure 20 shows the optimum rotation in terms of aiming distance; that is, the distance from the sign to the point on the road toward which the sign should be aimed. For example, for optimum performance of thin lens-mirror material on a 4-degree right curve the sign should be aimed at a point about 400 ft back on the road. If the sign is aimed as indicated in Figure 20, the luminance will be approximately the same as if the material were not sensitive to changes in entrance angles and the detrimental effect of the curve on the luminance of the sign will be negated. For left curves no significant loss in luminance is encountered at any distance if the sign is aimed as suggested by Figure 20. For right curves the only significant decreases in luminance are found beyond about 600 ft on 4-degree curves and beyond about 500 ft on 6-degree curves. In no case, if the sign is so aimed, does curvature reduce the long-range luminance to that of the next bright material, beaded sheeting.

In practice, of course, it would be impractical to aim the sign exactly as specified in Figure 20; the purpose of the curves is to illustrate how the relationship between rotation and luminance could affect signing practice. In erecting signs of materials sensitive to changes in entrance angle, it is suggested that the sign be aimed toward the point where it should be read. However, for 5- or 6-degree right curves it is suggested that the sign be aimed at a point no farther than 400 or 500 ft down the road to avoid serious loss in luminance at near distances. If these recommendations are followed, there will be no serious loss of brightness on curves of less than 6 degrees if a material such as thin lens-mirror is used. There is need for further research on curves sharper than 6 degrees, and on other materials sensitive to changes in entrance angle.

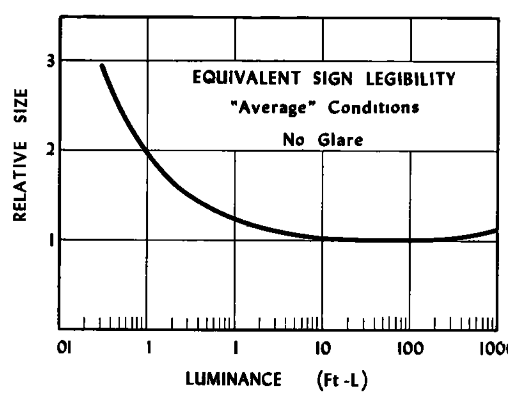

Figure 21. Effect of size on sign legibility under "average" no-glare conditions.

RELATIONSHIP OF LEGIBILITY AND LUMINANCE

With all other factors constant, the brightness or luminance of a sign has an important bearing on the size of the sign required for legibility. Certain basic data on the relationships between brightness and legibility have been presented (1).

Figure 21 expresses an estimate of the relationship between sign luminance and the relative sign size required for equal legibility. The curve was derived from an extension of laboratory data (1).

Field validation of the laboratory legibility data has not yet been undertaken. Since the curve in Figure 21 is subject to change and refinement, it should not be used for design purposes. Furthermore, the curve is for "average" no-glare conditions, and does not show the important effects that some factors (such as stroke width, black-on-white vs. white-on-black) have on legibility. However, the basic relationship shown in Figure 21 illustrates a fundamental concept in reflectorized sign design. For example, if a given sign can just be read when its luminance is about 50 to 100 ftL, it would need to be about twice as large if its luminance were only 0.1 ftL. The significance of this concept is shown by relating basic legibility data to those developed herein, as is done in the following examples.

Suppose that a comparison of sign designs is desired for a straight road application where traffic predominantly will be using lower beam. Assume that the sign is to be read at 500 ft. From Figure 12, the luminance of beads-on-paint type material is 0.06 ftL; that of flat sheeting or thin lens-mirror types is 0.9 ftL. From Figure 21, the corresponding relative size factors for equal legibility are 2.4 and 1.2, respectively. Therefore, at 500 ft any sign dimension of the less bright material would need to be 2.4/1.2 or 2.0 times larger for equal legibility with the brighter materials. The required sign area is $(2.0)^2$; hence, for the less bright material to be of equal legibility about four times as much sign material would be needed. From an economic point of view, the average annual unit cost (per square foot) in service of the brighter materials could be as much as four times that of the beads on paint.

Consider another example under the same conditions except that the sign is to be read at a distance of 200 ft. The luminance of beads-on-paint type material is 0.3 ftL; that of flat sheeting and thin lens-mirror types is 2.0 ftL. These luminances have corresponding relative size factors of 1.6 and 1.1. Therefore, at 200 ft each dimension of a beads-on-paint sign would need to be 1.6/1.1, or about 1.4 times larger than a sign of brighter material to be equal in legibility. The required sign area is $(1.4)^2$, or about twice as much. If the annual unit cost for the less bright material were less than one-half that of the brighter materials, it would be more desirable from the economic point of view.

Once again, it is pointed out that the legibility-brightness data referred to have not yet been developed sufficiently to permit application in design specifications, and the illustrations are given only to explain a basic concept of sign design.

SUMMARY AND CONCLUSIONS

A method has been described by which the luminance or brightness of a sign in place on the highway can be computed by taking into account (a) the position of the sign with respect to the pavement, (b) the distance between the headlamp and the sign, (c) vertical and horizontal curvature of the roadway, (d) laboratory photometric measurements of sign materials, and (e) the illumination reaching the sign from headlamps. Five common types of reflective materials were studied and their brightness values for representative highway situations were computed.

Although the results presented pertain to common highway sign applications, the same methodology could be applied to atypical vehicles (sports cars, buses), or other craft (airplanes, ships). It could also be applied to related problems (reflectorized pavement markings, advertising signs) and to a study of reflector buttons.

In general, highway signs have low luminance at near distances, maximum luminance at distances from 150 to 500 ft, and decreasing luminance at greater distances. Letter size is a factor of great importance in the selection of reflective material. For signs with small letter size, little is gained by using expensive high-brightness materials, because (a) small letters cannot be read at great distances no matter what their brightness, (b) adequate brightness is easily achieved using any material at near distances where illumination from headlamps is high, and (c) little increase in sign luminance is achieved through high-brightness materials because of the large divergence angles encountered at short distances. For large signs to be read at great distances, however, the more expensive materials may be more economical. Since little light reaches the sign from the headlamps, high-brightness materials are needed to achieve adequate luminance for good legibility.

Height of the sign is a more important factor than lateral placement. Overhead signs have luminances so much lower than roadside signs that they deserve special consideration.

For a sign mounted beyond a summit, sign luminance is always greater than on a level road. This would be the critical position for a material which might be too bright for good legibility. For a sign mounted beyond a sag, however, luminance is always less, and significantly so if the vertical curvature is abrupt or if the sign is to be read at a long distance. Vertical curvature can be a definite limitation on the placement of signs.

Horizontal curves cause marked reductions in sign luminance. Because signs on curves are outside the main portion of the headlamp beam, the illumination reaching the sign is reduced to as low as one-fourth of the straight-road value on a 6-degree curve. On horizontal curves a special problem arises from the use of reflective materials sensitive to changes in entrance angle. On a straight road, care should be taken to orient the sign within ± 5 degrees, or certainly within 10 degrees, of right angles to the road. Reasonably competent workmen should be able to orient the sign within these limits if given proper instructions. On vertical curves the problem of entrance angles is similar to that of a straight, level road, but on horizontal curves lack of care in aiming can result in a serious loss of brightness. With optimum orientation of the sign on horizontal curves, no serious loss of brightness need be encountered, at least for curves as sharp as 6 degrees.

Because luminance affects legibility, and since position and distance have great effects on luminance, it follows that position and distance should receive important consideration in the selection of the material used for particular sign applications. A fundamental concept of sign design necessary in order to make an objective comparison of sign materials for particular applications involves first equating of materials on the basis of legibility, and then taking into account average annual costs of satisfactory service.

It is important that field legibility studies take account of the luminance of the sign at the moment it is read. Unless this factor is considered, the validity of any generalizations concerning legibility will be open to question.

Further Research Needed

In addition to an extension of legibility studies, including field validation in which luminance is measured, further research is needed in several other areas relating to the problem of night performance of signs, as follows:

1. Study of the differences of headlamp illumination caused by such factors as misaim, voltage changes, sampling variation, age, dirt, and differences in manufacturing methods.
2. Quantitative measurement of the effects of age, rain, dew, fog, snow, and dirt on the reflective characteristics of various materials.
3. Study of the legibility of button-type letters and symbols, taking into consideration photometric factors.
4. Extension of the data presented in this paper to include other sign positions (such as turnpike locations). Further data are also needed on the effects of sign rotation and highway curvature on materials sensitive to entrance angle. After further precise data are developed, approximations permitting sufficient accuracy for estimating luminances for any material, position, etc., should be worked out for use in sign design.

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APPENDIX A

PHOTOMETRIC MEASUREMENTS OF MATERIALS

Specific Intensity

Previous studies of the photometric characteristics of reflective materials have used specific intensity as the unit of measurement (9, 3, 6). Specific intensity is defined as the apparent candlepower per unit of illumination of a specimen of material viewed as a point source. This unit of measurement is applicable to reflector buttons and to signs at such great distances that they appear as a point of light. At distances at which signs can be read, however, a sign cannot be considered a point source.

Specific Luminance

The legibility of a sign must be considered as a function of the luminance of the sign rather than of its intensity in apparent candlepower. The relationship between sign luminance and legibility has been outlined in a previous paper (1). The appropriate unit of measurement for this case is luminance per unit of illumination, measured in foot-Lamberts per foot-candle. A suitable name for this unit is specific luminance.

The relation between specific intensity and specific luminance is given by:

$$L = I\left(\frac{144\ \pi}{A\cos\ \phi}\right)$$

in which

L = specific luminance, in ft L per ft c;

I = specific intensity, in C per ft c;

$144\ \pi$ = constant for change of units

A = area of the specimen, in sq in.:

$\cos\ \phi = \cos\ (\theta + \Delta)$;

θ = entrance angle or angle of incidence; and

Δ = divergence angle.

In most practical cases ϕ is small, and specific luminance is approximately equal to 144 π times specific intensity per square inch.

The luminance factor of a body is defined as the ratio of its luminance to that of a perfect diffuser with the same conditions of illumination (10). Specific luminance is related to luminance factor by

$$L = \beta\ \cos\ \theta$$

in which

β = luminance factor; and

θ = entrance angle or angle of incidence.

Apparatus

The apparatus used for photometric measurements is shown schematically in Figure A1. The light source consisted of an automobile spotlight and a lens system to give an exit aperture of 1.2 in. The spotlight was operated at normal voltage and yielded a color temperature of about 2,900 deg K. A constant-voltage transformer was used to control light output. A corrected photocell (Weston) was used to measure the incident light on the specimen. A visual photometer with an objective lens (Luckiesh-Taylor Brightness Meter) was used to make direct measurements of the luminance of the surface of the specimen. The photometer reading in foot-Lamberts divided by photocell

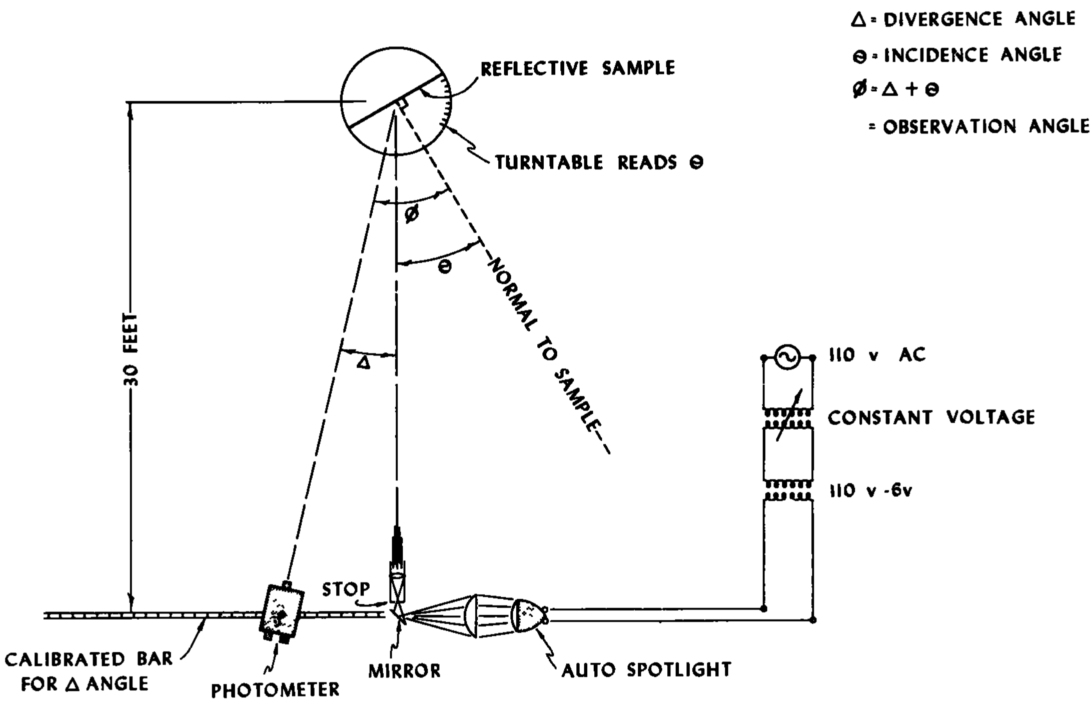

Figure A1. Schematic drawing of photometric apparatus used to measure reflective characteristics of materials.

reading in foot-candles yielded the specific luminance directly. (Careful cocalibration of photocell and photometer was essential for accurate results.) This method can be used only if the material has a surface of uniform brightness. Since only continuous-surface materials are considered in this report, the uses and limitations of this apparatus for testing reflector buttons are not discussed.

The apparatus is simple and relatively inexpensive. Other investigators (3, 6) have concluded that visual photometry does not yield accurate results; however, the authors' experience has shown that if the requirements for good visual photometry are met, accurate results can be obtained. The commonly used visual method requires the eye to match the point brilliance of the specimen with that of a comparison lamp. With the Luckiesh-Taylor instrument, however, the eye matches the luminance of an image of the specimen itself to the luminance of the photometer comparison field. This method gives smaller variation between readings and between observers. For a large number of measurements, the coefficient of variation between readings has not exceeded 2 percent for trained observers using a Luckiesh-Taylor meter. With the common visual method, substantial errors (and differences between observers) can be caused by the Purkinje effect when there is a difference in color between the specimen and the comparison lamp. In matching fields of brightness, however, errors due to the Purkinje effect can be avoided if image luminance exceeds 1 ft L (10). The apparatus used in this study more than meets this requirement.

Van Lear (9) and Finch (3) have pointed out the need for a large test distance, and suggested a distance of not less than 100 ft for testing reflector buttons. Use of a test distance as short as 30 ft introduces two sources of error. The first is the angular size of the light source and photometer apertures. The photometer used in this study had an aperture of about 6 minutes of arc, and the light source aperture was about 12 minutes of arc (comparable to a headlamp at about 150 ft). Apertures of these angles will introduce error of a moderate amount at small divergence angles (about the same amount of error as would be obtained with a 7-in. headlamp at 100 ft), but much less than some other methods in use (6, 4).

The second source of error lies in the failure of the inverse-square law to apply exactly at short test distances (9). The problem is analagous to the photometry of projectors. The minimum test distance is a function of the semi-divergence of the beam and the size of the individual reflector units. The reflector units of the materials considered in this report are many times smaller than those of reflector buttons: if 100 ft is adequate for reflector buttons, 30 ft is more than adequate for these materials.

Accuracy Check with Other Laboratories

For an evaluation of the accuracy of measurement, specimens from the same piece of material were sent to two other laboratories. It was found that their measurements compared favorably with those obtained in the authors' laboratory (see Figure A2). These laboratories were chosen because of their recognized standing and because they used two types of apparatus different from that of the authors. One laboratory (Electrical Testing Laboratories) used the standard visual method, wherein the point brilliance of the specimen at 100 ft was matched by a comparison lamp at the same distance. The second laboratory (University of California) used the photoelectric photometer described by Finch (3), and also used a test distance of 100 ft. All measurements were made at an angle of incidence of 10 degrees. The points plotted from the authors' data are the averages of five readings by one observer. A later check by another observer gave points which checked at least as well as those shown.

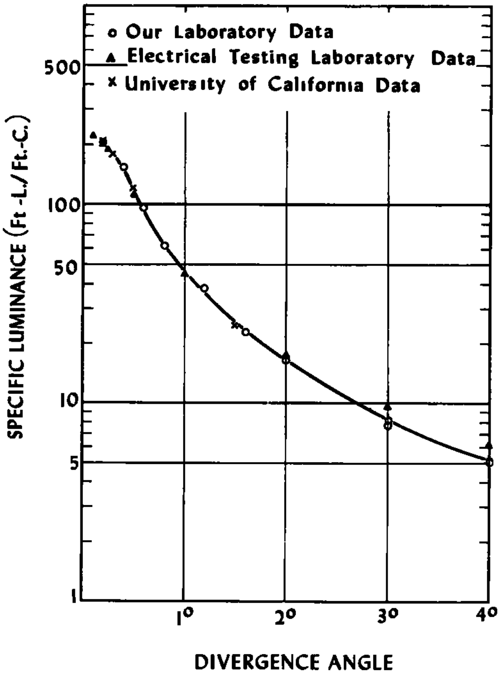

Figure A2. Comparison of photometric data from three laboratories.

It is felt that the accuracy is more than sufficient for the purposes of this paper. In the range of important divergence angles, there were no significant differences between the measurements by the three laboratories. At 3-degree and 4-degree divergence angles, the two visual methods differ significantly. Since the photoelectric apparatus did not give measurements at these divergence angles, no information could be obtained on which of the visual methods produced the correct results. However, since 3- and 4-degree divergence angles are encountered on the road only at distances less than 100 ft, the difference is of little practical significance.

APPENDIX B

TRIGONOMETRIC RELATIONSHIPS

To apply laboratory photometric measurements of reflective materials to practical highway situations, it was necessary to take into account the trigonometric relationships between the driver, the sign, and the headlamps of the car approaching the sign. Fundamental to the trigonometry of the problem were the dimensions of the car itself. Measurements were taken of 15 late model cars and averages were computed of all key dimensions. The "average" car dimensions used in this study are shown in Figure B1. The right headlamp was assumed to be 2.0 ft horizontally from the edge of the pavement in all computations.

Symbols Used

In the formulas developed, the following symbols were used:

- S = headlamp-to-sign horizontal distance, measured parallel to roadway;
- d = horizontal distance from the right headlamp to the sign, measured perpendicular to the roadway (see Fig. B1);
- h = height of the sign above the road (see Fig. B1);
- a = direct headlamp-to-sign distance, oblique in three dimensions;
- b = direct eye-to-sign distance, oblique in three dimensions;
- c = direct eye-to-headlamp distance, oblique in three dimensions;
- k = headlamp-to-sign distance when headlamps are abreast of the sign, oblique in two dimensions;
- Δ = divergence angle, the angle at the sign between the line from the headlamp to the sign and the line back to the eye, measured in the oblique plane which includes those three points; and
- θ = entrance angle or angle of incidence, the angle at the sign between the line from the headlamp to sign and the line normal to the sign, measured in the oblique plane including that line and point.

Car on a Straight Level Road

By three-dimensional application of the Pythagorean theorem, using the parameters based on a car of the dimensions shown in Figure B1, the following relationships were derived:

$$a^2 = S^2 + d^2 + (h - 2.7)^2 \text{ for right light}$$

$$a^2 = S^2 + (d + 4.8)^2 + (h - 2.7)^2 \text{ for left light}$$

$$b^2 = (S + 7.0)^2 + (d + 3.7)^2 + (h - 4.3)^2$$

$$c^2 = (7.0)^2 + (3.7)^2 + (1.6)^2 = 65.25 \text{ for right light}$$

$$c^2 = (7.0)^2 + (1.1)^2 + (1.6)^2 = 52.77 \text{ for left light.}$$

Headlamp Angles

To use the isocandle diagrams for determining illumination (see Appendix C), it was necessary to know the horizontal and vertical angles from the headlight to the sign. These were computed as follows:

$$\tan H = \frac{d}{S} \text{ for right headlamp}$$

$$\tan H = \frac{(d + 4.8)}{S} \text{ for left headlamp}$$

$$\tan V = \frac{(h - 2.7)}{S}$$

Entrance Angles or Angles of Incidence

For a sign mounted plumb and perpendicular to the roadway, the entrance angle or angle of incidence is given by

$$\tan \theta = \frac{k}{S}$$

in which

$$k^2 = d^2 + (h - 2.7)^2 \text{ for right light}$$

$$k^2 = (d + 4.8)^2 + (h - 2.7)^2 \text{ for left light.}$$

Divergence Angles

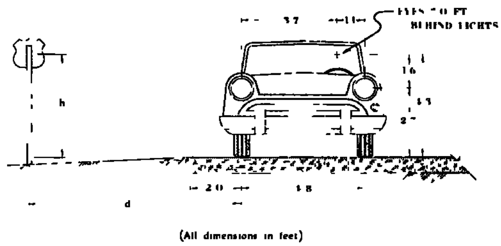

Figure B1. Dimensions of average car used in computations.

From the cosine law, the divergence angle is

$$\cos \Delta = \frac{a^2 + b^2 - c^2}{2\,ab}$$

For accurate calculation of the cosines of the small angles involved, the calculation of the denominator of this equation required the extraction of square roots accurate to ten decimal places. However, when the distance S to the sign becomes very large, the fact that the eye is 7 ft behind the headlamps becomes unimportant, and the divergence angle approaches, as a limit:

$$\tan \Delta = \frac{\sqrt{(1.1)^2 + (1.6)^2}}{S} = \frac{1.942}{S} \quad \text{for left light}$$

$$\tan \Delta = \frac{\sqrt{(3.7)^2 + (1.6)^2}}{S} = \frac{4.03}{S} \quad \text{for right light}$$

At such small angles the tangent and its angle are linearly related, so that

$$\Delta = \frac{111}{S} \quad \text{for left headlamp}$$

$$\Delta = \frac{231}{S} \quad \text{for right headlamp}$$

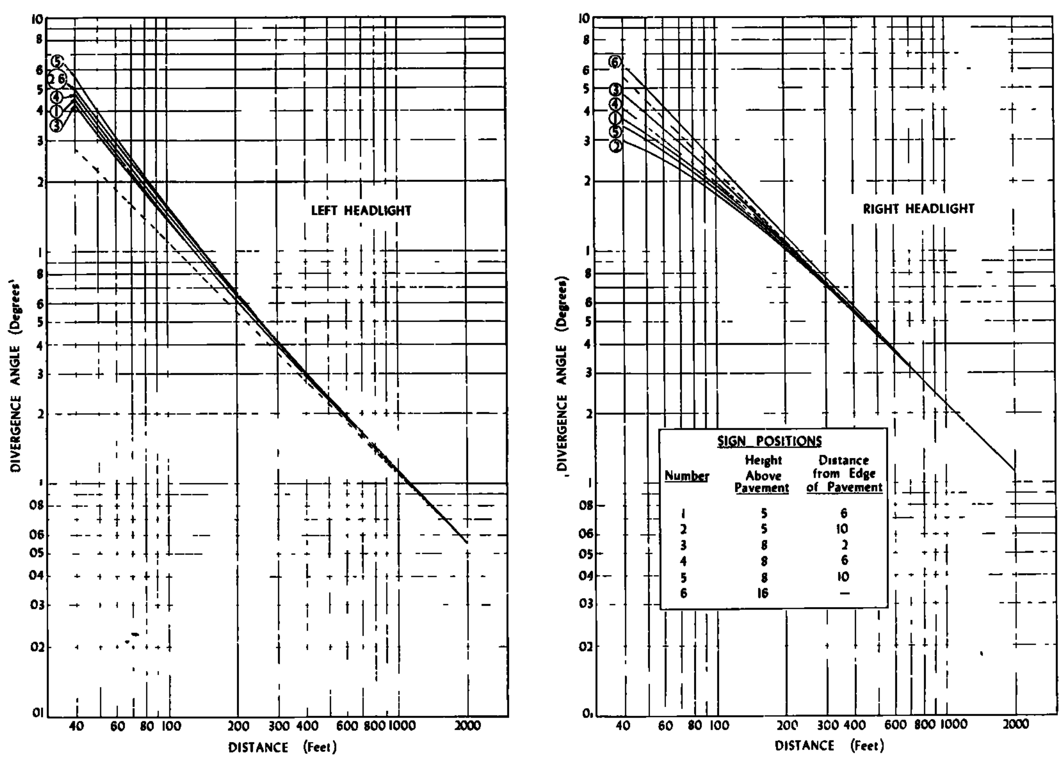

Figure B2. Divergence angles vs distance for left and right headlights of an average car for various sign positions.

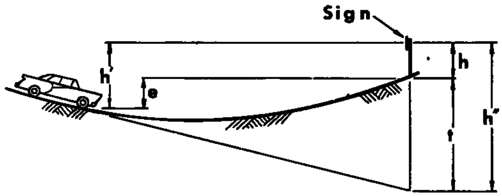

Figure B3. Geometry of vertical curves.

Figure B2 shows the computed values of the divergence angles plotted as a function of distance, for the six sign positions described in the text. The dashed lines show the long-distance approximations,

$$\frac{111}{S} \text{ and } \frac{231}{S}$$

Previous estimates of divergence angles by inexact formulas can be compared with these results. Finch (2) and Pocock and Rhodes (6) assumed a height of eye above headlamps of 21 in. Assuming the tangent of the divergence angle to be this separation divided by the distance to the sign, the divergence angle is approximately 100/S. Since height of eye above the headlamps is not the proper variable, these results were somewhat too low for the left headlamp, and less than one-half of the exact value for the right headlamp. Havens (4) used the cosine law for the special case where sign height and headlamp height are equal. Using somewhat different car dimensions, he obtained results for the right headlamp which agreed quite well with those in Figure B2 for sign position 1.

In future work approximations could be worked out, but should be evaluated in terms of the allowable error in the specific luminance for representative materials.

Truck on Straight Level Road

The trigonometric relationships for a truck approaching a sign are the same as for a car except that the parameters in the equations are different. Average values of measurements on a few late model trucks are given in Table 2 and compared with the values for the "average" car. Because of considerable variations in the dimensions of the few trucks measured, the truck values are not as reliable as those for cars.

Car on a Vertical Curve

Vertical curves were computed using the standard procedure for parabolic curves (5). The distance S was assumed as the horizontal distance. The geometry of vertical curves is illustrated in Figure B3. The difference in elevation, e, between the roadway at the sign location and the roadway at the car location was computed for each distance S. Divergence angles and incidence angles were calculated as for a straight road, except that h' was used in place of h, where

$$h' = (h + e) \text{ for sags}$$

and

$$h' = (h - e) \text{ for summits.}$$

As mentioned previously, headlamp angles are needed to use isocandle charts for determining illumination. The horizontal headlamp angle, H, for a vertical curve was the same as for a straight level road. To determine the vertical headlamp angle, V, it was necessary to project the tangent from the car to the sign, and compute the value of t in Figure B3. Headlamp angle V was computed in the same manner as for a straight level road except that h'' was used in place of h, where

$$h'' = (h + t) \text{ for sags}$$

and

$$h'' = (h - t) \text{ for summits.}$$

Computed solutions for the vertical

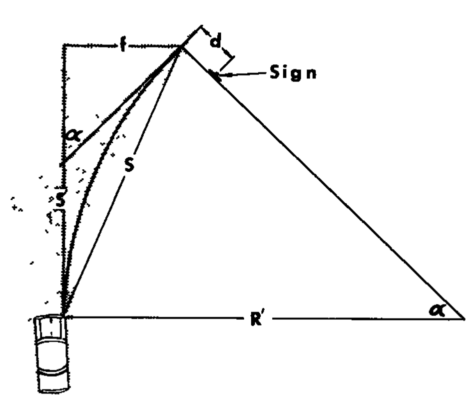

Figure B4. Geometry of horizontal curves.

TABLE 2

COMPARISON OF CAR AND TRUCK DIMENSIONS

(see Fig. B1)

Distances, ft	Car	Truck
Horizontal:		
Between headlamps	4.8	4.5
Eyes behind lamps	7.0	7.1
Right lamp from pavement edge	2.0	2.0
Line of sight from right lamp	3.7	3.3
Line of sight from left lamp	1.1	1.2
Vertical:		
Headlamp above pavement	2.7	3.4
Eyes above headlamp	1.6	3.5
Eyes above pavement	4.3	6.9

curves were checked by large-scale plots of the vertical curves on profile paper.

Car on Horizontal Curve

The geometry of horizontal curves is illustrated in Figure B4. The distance S was assumed as the chord distance on the path of the right headlamp. For a car and a sign both on a curve, the distance S corresponds to the distance S' on a straight road except for a greater lateral distance. The lateral distance to the sign is nearly equal to the sum of the distances f and d.

In highway engineering the degree of curve is defined as the central angle subtended by an arc of roadway 100 ft in length (5). For example, on a 3-degree curve the angle α would be 3 degrees when the arc distance at the centerline of the pavement was 100 ft. The radius of curvature can be found from

$$R = \frac{100 \text{ ft } (360^0)}{2 \pi D} = \frac{5729.58}{D}$$

where D is the degree of curve. On a 24-ft pavement with the right headlamp 2 ft from the edge of the pavement, the radius of curvature for the path of the right headlamp will be:

$$R' = (R + 10) \text{ for left curves}$$

$$R' = (R - 10) \text{ for right curves.}$$

Other necessary relationships are given by the following equations:

$$\alpha = 2 \sin^{-1}\left(\frac{S}{2 R'}\right)$$

$$S' = R' \sin \alpha$$

$$f = R' \text{ vers } \alpha$$

$$d' = (d + f) \text{ for right curves}$$

$$d' = (d - f) \text{ for left curves.}$$

Calculations of headlamp angles (for use on isocandle charts, see Appendix C) and divergence angles were made in the same manner as for a straight road except that the values S' and d' were used in place of S and d.

Calculations of entrance angles assumed that the sign was perpendicular to the roadway at the point of sign placement; in other words, that it is rotated through an angle α with respect to the car. For the sign position for which calculations were made (5 ft up and 6 ft from the edge of pavement) it was found that the vertical component of the entrance angle was negligible. In this case, the entrance angle is

$$\theta = (H + \alpha) \text{ for left curves}$$

$$\theta = (H - \alpha) \text{ for right curves.}$$

APPENDIX C

COMPUTATION OF SIGN LUMINANCE

For the calculated values of entrance and divergence angles for a given sign position and distance (see Appendix B), the specific luminance was obtained from the curves

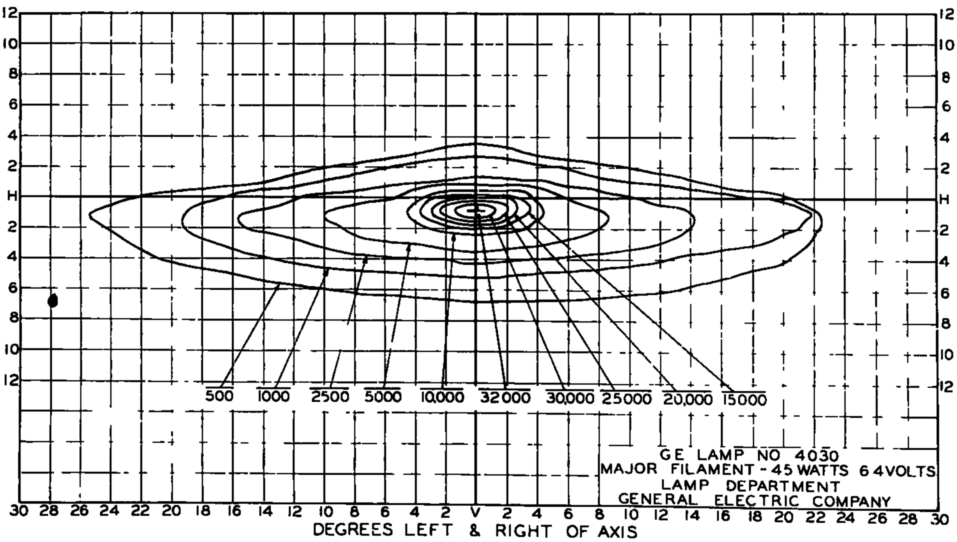

Figure C1. Example of isocandle chart showing headlamp candlepower distribution for upper beam of No.4030 headlamp. Similar charts were used for No.4030 lower beam and for No.5040 upper and lower beam.

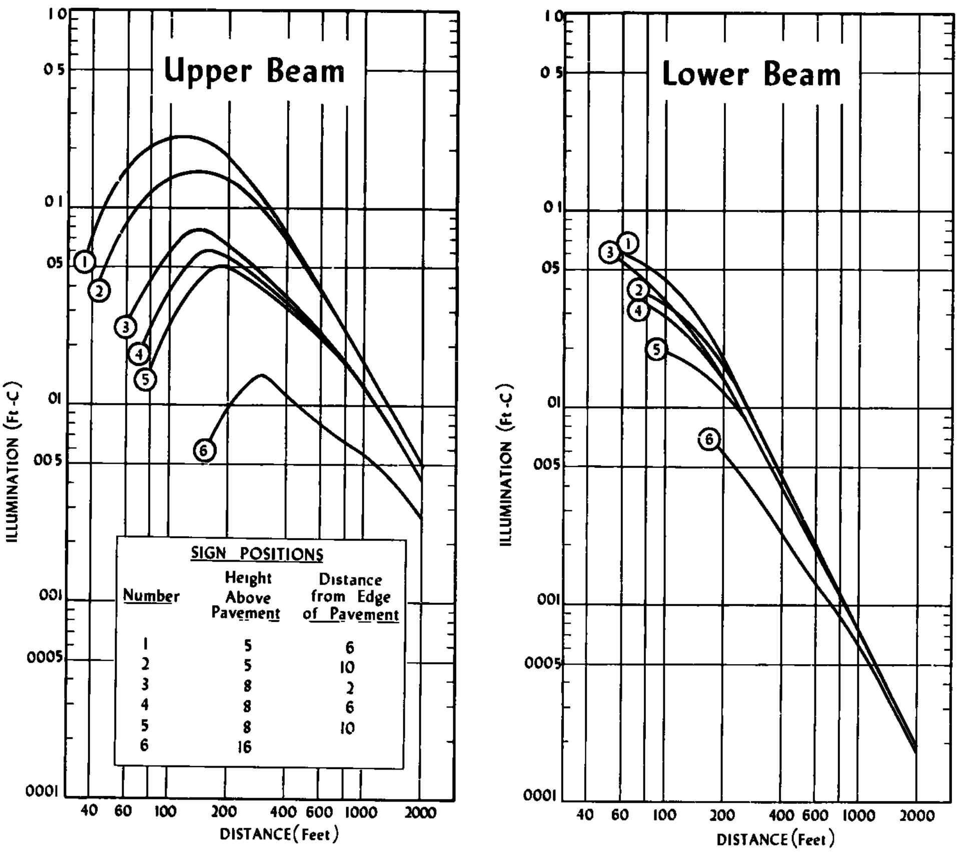

Figure C2. Illumination vs distance for various sign positions. Data shown are for a No.4030 right headlamp only, mounted in an average car.

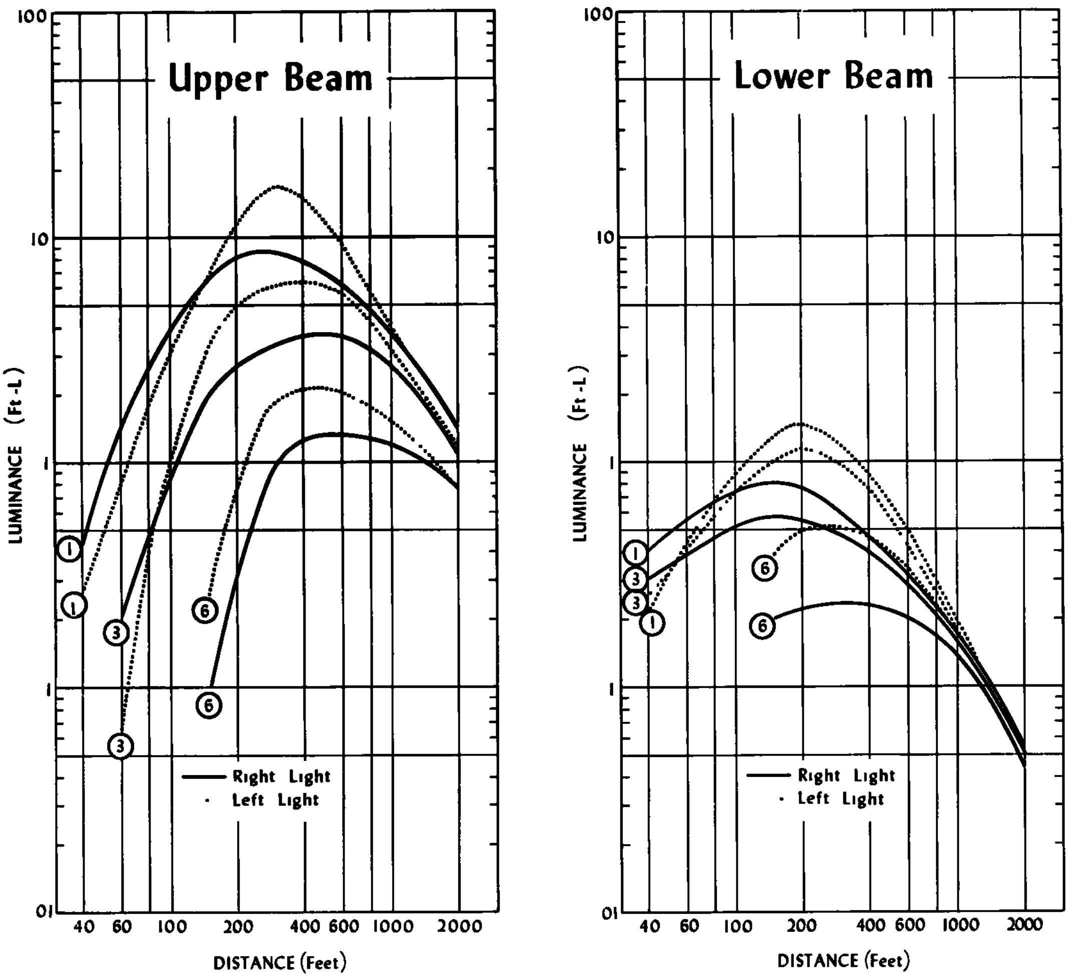

Figure C3. Luminance vs distance for left light and right light separately. Numbers on curves indicate sign positions.

based on photometric measurements of the reflective material (see Fig. 10). The luminance of the sign was then found by multiplying this value in specific luminance by the illumination reaching the sign from the headlamp.

The illumination was determined by the use of isocandle charts such as the one shown in Figure C1. These curves were supplied by the manufacturer as representing typical average production.

The headlamp angles H and V were computed using trigonometric relationships of the car approaching the sign as explained in Appendix B, and were used to find the intensity of candlepower from the isocandle curves. The illumination reaching the sign was:

$$E = \frac{\text{candlepower}}{(\text{distance})^2} = \frac{\text{C. P. for H and V}}{a^2}$$

Use of S^2 instead of a^2 (see symbols in Appendix B) would result in negligible error except at short distances.

Figure C2 shows curves of the illumination from the upper and lower beam of a car's right headlamp reaching signs in various positions on a straight level road. Similar illumination curves were plotted for the left headlamp, for the new No. 5040 headlamp, for trucks, and for vertical and horizontal curves.

Figure C3 shows the luminance for flat sheeting material, for left and right headlamps separately. In the computations it was necessary to treat each lamp separately because differences in illumination and differences in the geometry of divergence angles and entrance angles result in different luminances for each lamp. The total luminance of a sign as seen by a driver is the sum of the luminances for the two headlamps. Except for Figure C3, which illustrates the difference in luminances for each lamp, all of the luminance data in this paper are shown as the sum from both lamps.

An Experimental Study of Four Methods of Reflectorizing Railway Boxcars

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● TWO years ago Stalder and Lauer (7) presented a study on the effective use of reflectorized materials on railway boxcars. This was the first time that a study of this nature, carried out with boxcars, had been reported. Hoppe (3) and later Hoppe and Lauer (4) showed that reflectorized materials on the back of trucks would greatly shorten the perceptual differential of distance between the driver and a vehicle ahead. Stalder and Lauer (5) had also shown that pattern distribution had a great deal to do with the effectiveness of illuminated surfaces of reflectorized material.

In the study of boxcars just discussed, two important conclusions were made: (a) the larger the patches of reflectorized material used, the lower the level of illumination needed, and (b) larger concentrations of a given amount of reflectorized materials are more effective than smaller ones.

In a bill introduced in Congress by H. R. Gross of Iowa, and from other recommendations made, it was stipulated that four-inch squares of reflectorized material be placed along the sill of the boxcar at distances of approximately four feet. In the absence of experimental data, this obviously was a best guess on the part of those who were advisers to the Congressman on this bill.

From the studies on boxcars already cited, it appeared that this kind of an arrangement would not be most effective. Consequently, for the purposes of the present investigation the following hypothesis was set up: For a given amount of reflectorized material an optimal utilization of this material must exist. It is axiomatic and well demonstrated that the use of reflectorized materials will help. The question to be answered is how can such reflectorized materials be used most efficiently.

PROBLEM AND APPARATUS

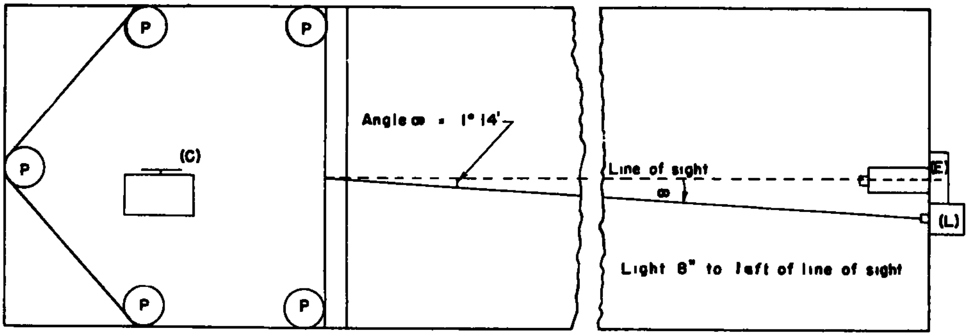
In the first study on boxcars already cited, three different groups of subjects were used for making the tests. Thirty, 30, and 25 subjects, respectively, were run. The subjects of each group were different and may conceivably have differed with respect to visual acuity, night vision, motivation, cultural background and other influences. It was thought desirable to set up the present study using a random-block design which would make possible the presentation of all conditions used to all subjects. By this design it was thought that 40 subjects would suffice to give adequate data for the purposes of evaluating the results found.

This first study has been described by Stalder and Lauer (7). Only a few statements will be made to orient those who are unfamiliar with the study.

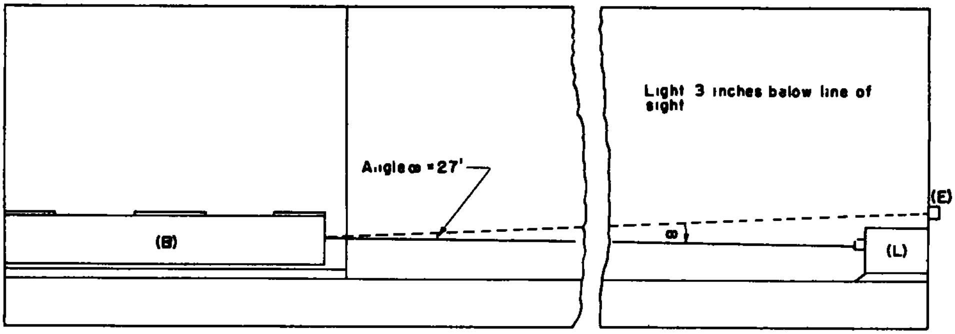
The Scotometer as designed by Stalder, Hoppe, and Lauer (6) was used with the Clason Acuity Meter as a source of illumination in the first series. For series two and three a Viewmaster Model S Projector was used as the luminant with a variac control.

In the first study (7) the distance from the eye of the observer to the stimulus belts was only 29 ft. It was impossible to get the projector located in such a fashion as to reduce the angle of viewing below 27 min. In the present study the distance from the subject to the stimulus object was lengthened to about 43 ft, 6 in. The same carrier for the belts in the first study was adapted for use at the end of the Scotometer tunnel to secure additional distance. Instead of a reversing motor which gave some difference in sound when the direction of rotation was changed, a ½ hp shifting-brush motor was employed and set so that the effective speeds could be established at any desired point.

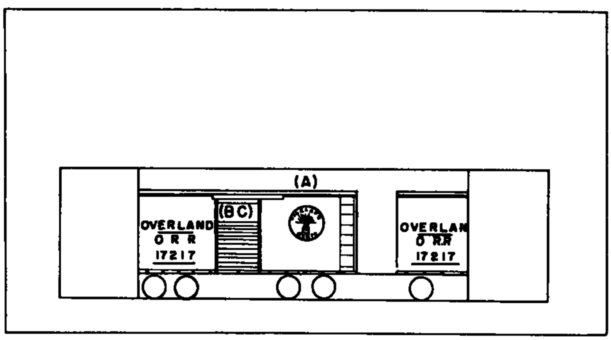
For the first study the belt was calibrated to run around 50-mph scale speed. In the present study the scale speed was set at 40 mph, as that speed was considered more typical of realistic situations than the 50-mph simulated speed. The results in observation apparently made very little difference at various speeds used in a pilot run.



A TOP VIEW SHOWING ANGLE BETWEEN LIGHT AND LINE OF VISION IN SERIES TWO



B SIDE VIEW SHOWING ANGLE BETWEEN LIGHT AND ANGLE OF VISION IN SERIES THREE



C CLOSE-UP OF APERTURE OPENING SHOWING SECTIONS OF TRAIN EXPOSED MOVEMENT WAS REVERSED IN RANDOM ORDER

Figure 1. The subject sits at the right with his eye at the scope (E). The two top sketches A and B show the experimental conditions used in Series 2 and Series 3 respectively. The lower sketch C shows the aperture and reproduction of lettering used on the boxcars. It will be noted that the Overland Route mark is several times larger than the small sill markers. The cross-bars below (BC) on the door were quite subdued and were not noticeable as in the drawing.

Also the signal system between the experimenter and subject was changed somewhat and a double lighting system was placed on the Scotometer panel with thumb switches at each side of the observer. Instead of asking only for a response of "right" or "left" in the present study, the subject was instructed to not only respond but to press the key to the side in which direction the train was moving. Thus if the train were first observed to be moving to the right, he pressed the right-hand key and at the same time called out "right." If the train were observed as moving to the left, he pressed the left-hand key

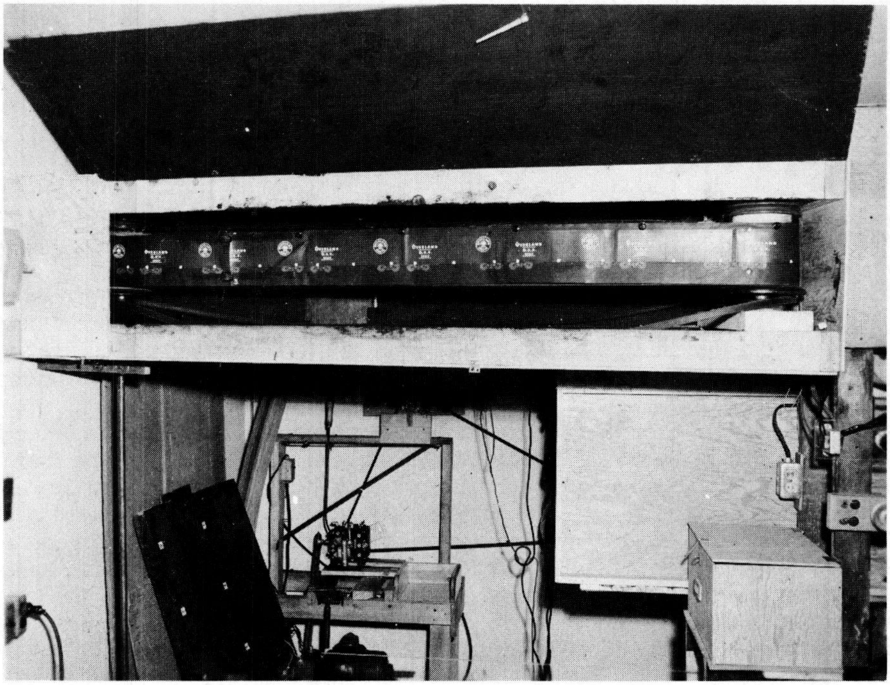


Figure 2.

and at the same time responded by saying "left."

The guide lights were in such a position that the experimenter, who was adjusting the shutter at a gradual rate of change, was able to catch the response both auditorily and visually and thus avoid any reasonable chance of error. A test of the reliability of dial readings from the shutter showed these to be of the order of .96 and above. This was in agreement with the earlier study in which the reliability of observations was found to run about .97. To get this reliability, 10 readings on each belt were made and the first 5 correlated with the second 5. Very slight practice effect was noted.

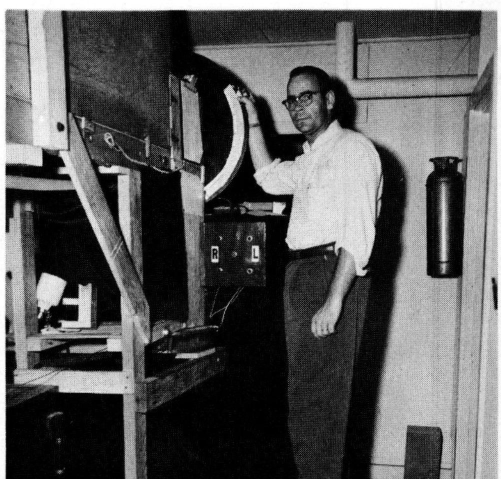


Figure 3.

PROCEDURE AND DESIGN OF THE STUDY

The procedure consisted of giving each subject 10 trials on each of 4 belts, all having the same amount of reflectorized material on the side of the cars. Belt #1 had one large square of reflectorized material placed in the middle of the car. Belt #2 had 2 square pieces of reflectorized material, each ½ the area of 1, located towards each end of the car. Belt #3 had 3 square pieces, each ⅓ the area of 1, placed along the side of the car—one in the middle and one towards each end. Belt #11 had 11 small markers, each $\frac{1}{11}$ of the area of #1, placed along the sill of the car. (See Figure 1)

No other reflectorized materials were used on the side of the car for this set of experiments. Thus the 4 belts were given to each subject in randomized order and so set up that each would have approximately the same number of 1st, 2nd, 3rd and 4th positions in the set of trials. In this way any systematic error such as practice effect which might appear could be minimized.

One other additional feature was added in the present experiment. It is a well known fact to psychologists that the autokinetic illusionary movement might well enter into any such experiment, at least theoretically. In order to minimize this possibility, or at least to keep the apparent fixation point constant, a very small dim red light was placed just below the reflectorized portions of the passing belt. The belt was carried by three pulleys and passed across the aperture directly at right angles with the line of vision of the subject. Having this small, dull red light just below the point of observation and instructing the subject that he was to fixate this light at all times, the possibilities of any autokinetic effect were at least minimized with respect to the reflectorized patches on the box cars.

The general design of the study has been described for the most part as being that of a random block and the procedure being that of having each subject view the four belts successively. Ten readings were made on each belt and the mean of these 10 readings used as a score for each belt.

Each subject was also given a night vision test. All subjects had fairly good acuity and none was below average. This and other factors, of course, were experimentally controlled by the design of the experiment.

In a repetition of such a study it would probably be advisable to measure also the daytime acuity by precise methods. While it would not affect this experiment, the data would be of interest.

Each subject thus made at least 40 observations which were recorded. Two or 3 preliminary trials are given to familiarize each subject with the experiment. After being placed in the apparatus, and being allowed to dark-adapt for 4 or 5 minutes, the directions were read to the subject and he was given the preliminary trials.

In all, there were 1600 observations made which served as a basis of the statistical analysis of this study. Reliabilities for the readings on each belt were computed and are shown in Table 1.

TABLE 1

RELIABILITY OF READINGS FOR EACH BELT

Belt #11 (11 small markings on sill)	.88
Belt #3 (3 markings, one at center and one each end)	.96
Belt #2 (2 markings, one at each end)	.97
Belt #1 (1 marking in center)	.94

The first 5 trials were correlated with the second 5 trials and corrected by the Spearman-Brown formula. Belt #11 was least reliable, probably due to the difficulty inherent in the marking as found from this experiment.

TABLE 2

REFLECTORIZATION OF BOXCARS INTERCORRELATIONS BETWEEN SCORES MADE ON BELTS

N = 40

Belt	11	3	2	1
1	.5823	.7997	.8110	.94
2	.6965	.8701	.97	---
3	.6727	.96	----	
11	.88	----		

TABLE 3

DIFFERENCE IN MEANS IN UNITS OF CALIBRATED LIGHT

	11	3	2	1
Mean light units	21.24	7.38	7.44	5.95
1	15.29[a]	1.43	1.49	----
2	13.80[a]	0.06	----	
3	13.91[a]	----		
11	----			

[a] Significant at the 1 percent level of confidence. Others are not significant above the 15 percent level of confidence.

Two methods of analysis were applied and the results from both were considered. Since the subjects were common there was a correlation between the observations between scores made in the belts. These had to be partialled out, and after using a method proposed by Duncan (1) for analysis of variance, the older formula conventionally used for determining the significance of differences

$$S.D.\ diff = \sqrt{S.D.\ m1^2 + S.D.\ m2^2 - 2 r_{12} \times S.D.\ m1 \times S.D.\ m2}$$

was finally adopted as the check on the first method used. It is somewhat more precise. See Garrett (2).

RESULTS OBTAINED

From the first analysis, using the multiple range and multiple F test, it was found that only certain belts showed a significant difference. All three belts, #1, #2, and #3, yielded a highly significant difference when compared with belt #11.

However, in this analysis it was felt that with the use of more precise methods perhaps differences might be found between belts #1 and #2, and between belts #1 and #3. The computations were made and the results are given in Table 2. The difference between pairs of belts are given in Table 3.

APPLICATIONS

The difference noted for the best application, belt #1 which required 5.95 units of light as compared with the poorest application, belt #11 which required 21.24 units, gives a ratio of 3.57. Converted into distance at 1000 ft for a standard high-beam headlight of 75,000 bcp, this would be equivalent to a distance of 889 ft. If considered at a relative distance of 500 ft, the disadvantage would amount to 444 ft.

Even at 100 ft, which is a very short distance and far below the stopping distance at ordinary road speeds, the added increment needed for equivalent perception time would be almost 89 ft—about 1 second in terms of time at 60 mph. Hence, the advantage of single large reflectorized area becomes obvious. These calculations are based upon the assumption that the differentials in lighting have relative effectiveness at different levels of illumination.

SUMMARY AND CONCLUSIONS

1. Forty subjects were used in an experiment to determine the differences between 4 different types of belts reflectorized in different ways to represent miniature scale-size trains. The results generally confirm the hypothesis set up that a mass application of reflectorized material is superior to a distribution of the same material.

2. Belt #11 seemed to be inferior, partly because the retinal image lag tends to produce the effect of a line which could not be distinguished as moving across a space within the critical angle of incident light falling on the side of a train.

3. By the most precise statistical methods available, and with the number of cases involved, the differences between belts #2 and #3 were not significant. The differences between belts #1 and #3, and #1 and #2 were not substantial. This narrows down the problem to the two or three possibilities—one, two or three patches of reflectorization on the side of each car.

Further studies are being made of the relative effect of vertical strips and square patches of equal dimensions.

ACKNOWLEDGMENT

The study reported here was made possible through a grant from the Minnesota Mining and Manufacturing Company to the Driving Research Laboratory, Iowa State College.

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Effect of Street Lighting on Night Traffic Accident Rate

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● IN many large cities throughout the country, studies have been made to determine what effect the illumination of a roadway has upon the nighttime accident rate. The task is quite difficult under normal circumstances because of the presence of other variable factors which also influence the nighttime accident rate. However, by careful analysis of traffic accident records, it is possible to show that accident rates at night are decreased as a result of improved lighting conditions or, in other words, higher levels of illumination.

By examination of traffic accident reports received from the Traffic Section of the Chicago Park District, it is possible to show graphically the value and importance of higher levels of street lighting in reducing the nighttime accident rate. Examination of Figure 1 shows that on Michigan Boulevard between the river and 12th Street where the average lighting level was 0.144 foot-candles, the night accident rate per million miles of travel for all accidents is 17.9. Between 12th and 16th where the light level was 0.350 foot-candles, the accident rate is 11.9, and in the section from 16th Street to 22nd Street which has an average lighting level of 0.88 foot-candles, the accident rate is 9.5. Therefore, a definite tendency to reduce the nighttime accident rate by increasing the average lighting level is observed. This is a boulevard on which the various sections fall in the same general classification in relation to vehicle miles traveled; that is, having more than 10 million vehicle miles of travel per year. The type of lighting installation which existed in 1949 on each of the sections mentioned is listed below:

MICHIGAN BOULEVARD

Each Fixture - SECTION:	River to 12th Street - 6-1,000 lumen incandescent lamps
	12th to 16th Street - 10,000 lumen incandescent lamps
	16th to 22nd Street - 20,000 lumen mercury vapor lamps

NIGHTTIME ACCIDENTS PER MILLION VEHICLE MILES TRAVELED ON SECTIONS OF MICHIGAN AVENUE
From September 1st, 1948, through August 31st, 1949

			Accidents				Accidents Per MVH			
	MVM	Light Level[1]	F	NF	PD	T	F	NF	PD	T
River to 12th St.	9.27	0.144	1	34	131	166	.1	3.7	14.2	17.9
12th to 16th	2.44	0.352	0	14	15	29	0	5.7	6.1	11.9
16th to 22nd	1.89	0.880	0	6	12	18	0	3.2	6.3	9.5

SYMBOLS

MVM	Million Vehicle Miles	P.D	Property Damage
F	Fatal Accidents	T	Total
NF	Non-Fatal Accidents	1	Foot-candles

The diagram shown on Figure 2 indicates the fatal and non-fatal night accidents that were saved as a result of improved lighting. Accident data were obtained for a particular section of Michigan Boulevard and a comparison was made of accidents which occurred before relighting (1947) and after relighting (1949). The daytime accident rate for 1949 was approximately 100 percent greater than that for 1947, as a result of the increase in traffic volume. The main factors which would cause a variation of the nighttime accident rate are traffic volume and level of illumination.

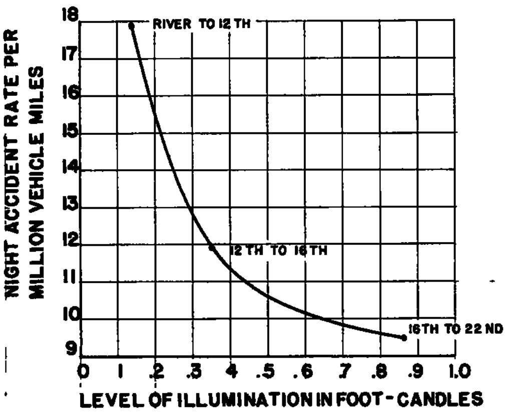

Figure 1. Trend in nighttime accident rate under various levels of illumination for one year ending August 31st, 1949, Michigan Boulevard.

A 19-year record for all boulevards and drives of the Chicago Park District shows that the increase in traffic volume at night results in an increase of the night accident rate in the same proportion as the day rate.

Prediction of future accidents based on this correlation shows that the nighttime accident rate for 1949, without improved lighting, would have been approximately 13.3. Traffic records reveal that the night rate for 1949 was actually 2.49. Therefore, as a result of improved lighting, an 81 percent saving in fatal and non-fatal accidents was realized.

Figure 3 illustrates the savings in nighttime property damage accidents which may be accredited to improved lighting. The same prediction made for Figure 2 applies; that is, without improved lighting the night accident rate for property damage accidents in 1949 would have been increased by the same proportion of increase that occurred in daytime property damage accidents. Although the graph shows an increase in night accidents for 1949, the increase is, nevertheless, considerably lower than the expectancy. By the prediction made, the expectancy would be 17.0 property damage accidents per million vehicle miles. The actual rate from traffic records was 6.96. Therefore, the savings as a result of increased illumination is found to be approximately 61 percent.

Examination of the overall or total night and day accident rates for two adjacent sections of Michigan Boulevard which were re-lighted, reveals the following:

Section		Accident Rates Per Million Vehicle Miles	
		Daylight	Dark
12th to 16th St.	1947	3.6	9.8
	1949	9.4	7.3
16th to 22nd St.	1947	4.84	12.74
	1949	12.80	9.45

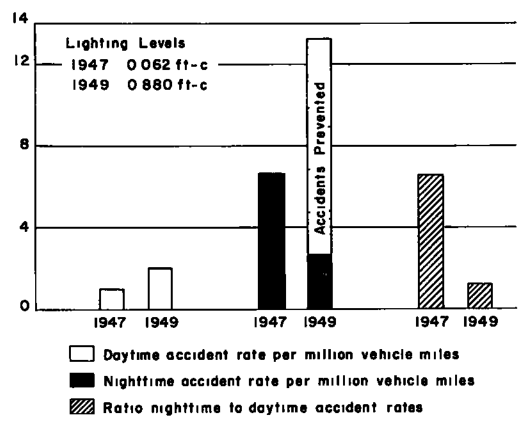

Figure 2. Effect of improved lighting upon fatal and non-fatal accidents. Michigan Blvd., 16th to 22nd.

The expectancy of nighttime accidents for 1949, applying the same prediction made previously, would:

12th to 16th Street:

Ratio of daylight increase (1949 to 1947)	$\frac{9.4}{3.6}$ =	2.6
Expectancy of nighttime accidents, 1949 is	9.8 x 2.6 =	25.5
Actual rate for 1949 was	7.3	
Percent saving as a result of improved lighting was.......	$\frac{25.5-7.3}{25.5}$ =	71.5%

16th to 22nd Street:

ACCIDENTS

	DAYLIGHT				DARK			
	F	NF	PD	T	F	NF	PD	T
Before (1947)	0	4	15	19	0	12	11	23
After (1949)	0	9	47	56	0	5	14	19

ACCIDENT RATE PER MILLION VEHICLE MILES

	DAYLIGHT					DARK				
	MVM	F	NF	PD	T	MVM	F	NF	PD	T
Before (1947)	3.93	0	1.02	3.82	4.84	1.80	0	6.65	6.09	12.74
After (1949)	4.38	0	2.06	10.74	12.80	2.01	0	2.49	6.96	9.45

RATIO DARK TO DAYLIGHT PER MILLION VEHICLE MILES

	Fatal and Non-Fatal	Property Damage	Total
Before(1947)	6.51	1.59	2.63
After(1949)	1.20	0.65	0.74

Ratio of daylight increase (1949 to 1947) .... $\frac{12.80}{4.84}$ = 2.64

Expectancy of nighttime accidents, 1949 is ....12.74 x 2.64 = 33.6

Actual rate for 1949 was 9.45

Percent saving as a result of improved lighting was... $\frac{33.6 - 9.45}{33.6}$ = 71.7%

A visual picture of the above results can be obtained by a study of Figure 4.

Cost of Relighting Chicago Park District Boulevards Compared to Savings Resulting from a Reduction in Nighttime Accident Rate

Costs set up by the National Safety Council released July 1954:

Each death	$22,600
Each non-fatal injury	1,250
Each property damage accident	190

Accident data obtained from Traffic Section of the Chicago Park District for the year 1949 for all boulevards.

Fatal	40
Non-fatal	1290
Property damage	4365

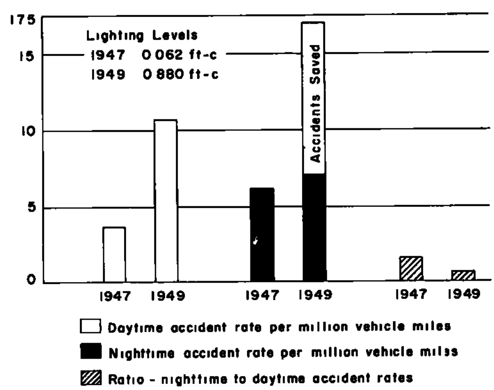

Figure 3. Effect of improved lighting upon property damage accidents. Michigan Blvd. 16th to 22nd.

The cost of relighting the Chicago Park District boulevards is indicated by a recently completed typical installation on which the costs were as follows:

Cost of Modernizing Lighting to Conform to I. E. S. Standards (American Standard Practice for Street and Highway Lighting)

PER LAMPPOST

	Material	Labor	Total
Lamppost complete, including luminaire, lamp and ballast	$260	$110	$370

	Material	Labor	Total
Lamppost foundation	22	80	102
Total - per lamppost	$282	$190	$472

PER MILE

	Material	Labor	Total
Lampposts complete, including luminaire, lamp and ballast	$13, 520	$5, 720	$19, 240
Lamppost foundations	1, 144	4, 160	5, 304
Total — Lampposts, per mile	$14, 664	$9, 880	$24, 544
On older boulevards considerable rebuilding of underground system was necessary			$18, 156
New cable and rearrangement of existing cables	3, 228	4, 956	8, 154
Total, Per Mile			$50, 884

For the following calculations we have used a round figure of $50, 000 per mile.

Cost of Nighttime Accidents

Fatal	40 at	$22, 600 =	$ 904, 000
Non-Fatal	1290 "	1, 250 =	1, 612, 500
Property Damage	4365 "	190 =	829, 350
	Total cost —		$3, 345, 850

Assuming, from results obtained in previous calculations, that approximately 70 percent of the nighttime accidents could be eliminated by improved lighting:

Possible annual saving—70 percent of $3, 345, 850 = $2, 342, 095.

Cost of Relighting 205 Miles of Park District Boulevards

Average cost of $50, 000 per mile multiplied by 205 miles—$10, 250, 000.

$$\text{Span of Program} = \frac{\$10,250,000}{\$\ 2,342,095} = 4.38$$

Therefore, in a period of less than five years, the complete cost of relighting all boulevards would be balanced by the savings in nighttime accidents.

The elimination of this menace to night driving and the essential planning of an extensive program of street relighting is a responsibility resting upon every citizen and all who are working in the best interests of the general public.

Table 1 shows the day and nighttime accident rate per million vehicle miles for the interim of 1936 to 1954, inclusive. It should be noted that there was a marked decrease in both the day and night accident rate during the war years, 1942 to 1945 inclusive, when highway speeds were limited to 35 miles per hour. It should also be noted that there has been a gradual reduction in the nighttime accident rates since 1950, at which time the effect of improved street lighting on the Park District

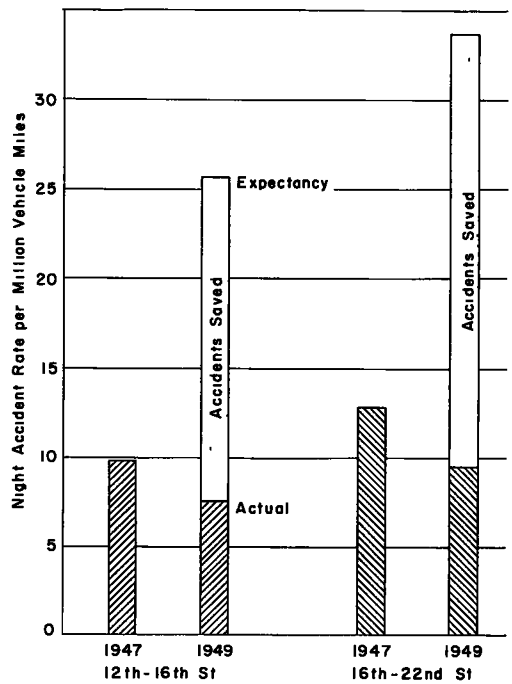

Figure 4. Effect of improved lighting upon total nighttime accidents, Michigan Blvd.

TABLE 1. — Chicago Park District, all Boulevards and Drives, Accident Rates and Vehicle Miles Traveled.

	DAYLIGHT									DARK									RATIO OF DAYLIGHT TO DARK			
	Millions of Vehicle Miles	Accidents				Accidents Pe Million Veh Miles				Millions of Vehicle Miles	Accidents				Accidents Per Million Veh. Miles							
Year		F	NF	PD	T	F	NF	PD	T		F	NF	PD	T	F	NF	PD	T	F	NF	PD	T
1936	643				4098				6 37	289				3382				11 70				1 84
1937	702				5283				7 53	316				4388				13 89				1 84
1938	704				4449				6 32	317				4122				13 00				2 06
1939	718				5541				7 72	323				4840				14 98				1 94
1940	764 3	28	1483	4480	5991	0 04	1 94	5 86	7 84	343 4	62	1757	3520	5339	0 18	5 12	10 25	15 55	4 50	2 64	1 75	1 98
1941	814 4	27	1588	4996	6611	0 03	1 95	6 14	8 12	365 9	69	1839	3728	5636	0 19	5 02	10 19	15 40	6 33	2 57	1 66	1 90
1942	656 6	14	1175	3242	4481	0 02	1 79	4 94	6 75	295 0	47	1295	2600	3942	0 16	4 39	8 81	13 86	8 00	2 45	1.78	1.98
1943	516 8	17	821	1883	2721	0 03	1 59	3 64	5 26	232 2	44	906	1569	2519	0 19	3 90	6 76	10 85	6 38	2 45	1 86	2 06
1944	518 7	17	814	1982	2813	0 03	1 57	3 82	5 42	233 0	47	969	1537	2553	0 20	4 16	6 60	10 96	6 67	2 65	1 73	2 02
1945	563 8	24	958	2142	3124	0 04	1 70	3 80	5 54	253 8	46	1095	1913	3054	0 18	4 32	7 55	12 05	4 50	2 54	1 99	2 18
1946	727 7	12	1244	3524	4780	0 02	1 71	4 84	6 57	326 9	66	1426	2863	4355	0 20	4 36	8 76	13 32	10 00	2 55	1 81	2 03
1947	803 2	26	1325	3962	5313	0 03	1 65	4 93	6 61	360 8	42	1581	3239	4862	0 12	4 38	8 98	13 48	4 00	2 65	1 82	2 04
1948	843 3	11	1374	4909	6294	0 02	1 68	5 82	7 47	378 9	47	1400	3818	5265	0 13	3 69	10 08	13 90	6 50	2 26	1 73	1 86
1949	893 6	15	1347	5852	7214	0 02	1 50	6 55	8 07	401 5	46	1378	4719	6143	0 12	3 43	11 75	15 30	6 00	2 29	1 79	1 90
1950	953 2	11	1486	7261	8758	0 01	1 56	7 62	9 19	428 2	44	1610	6118	7772	0 10	3 76	14 29	18 15	10 00	2 41	1 88	1.97
1951	971 0	19	1488	7528	9035	0 02	1 53	7 75	9 30	436 3	38	1511	6090	7639	0 09	3 46	13 96	12 51	4 50	2 26	1 80	1 88
1952	976 7	23	1592	7155	8770	0 02	1 63	7 75	8 98	438 8	39	1409	5091	6539	0 09	3 21	11 60	14 90	4 50	1 97	1 58	1 66
1953	996 7	11	1703	7230	8944	0 01	1 71	7 25	8 97	447 8	35	1462	5224	6721	0 08	3 26	11 67	15 01	8 00	1 91	1 61	1 67
1954	1024 4	22	1862	7419	9303	0 02	1 12	7 24	9 08	460 3	38	1469	4705	6212	0 08	3 19	10 22	13 49	4 00	1 75	1 41	1 49

Code F—Fatal, NF—Non Fatal, PD—Property Damage, T—Total

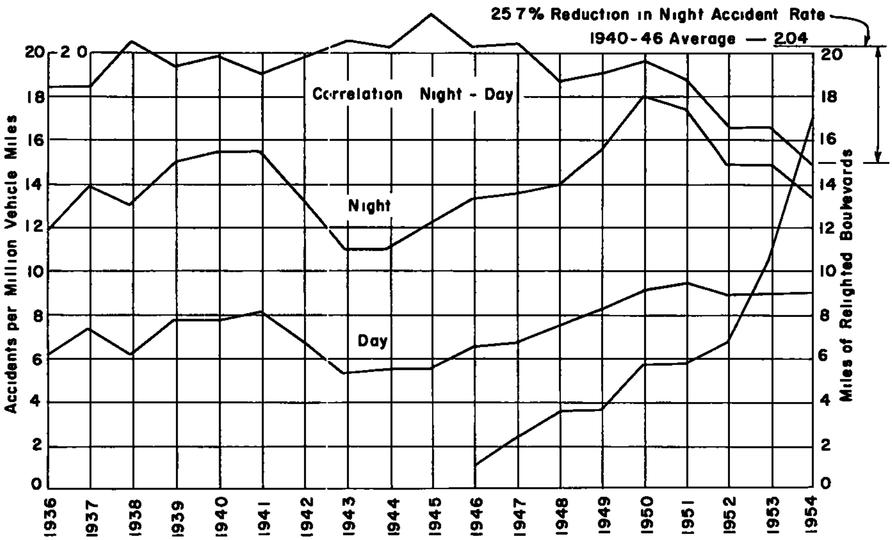

Figure 5. Accident rates for all Chicago Park District Boulevards and Drives.

boulevards began to show results. As the lighting on more park boulevards is improved, it is anticipated that there will be a continuing reduction in the night accident rate.

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A Configuration of Taillights and Brakelights

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●IN the course of preparing a pictorial review of signal lighting in connection with the celebration of the 50th anniversary of the founding of the Illuminating Engineering Society, the writer came to the realization that although brakelights have been in use for more than three decades, it is still common practice to depend upon a difference in intensity to distinguish them from taillights. This is a situation that certainly warrants consideration.

The apparent intensity, or brilliance, of any signal light is determined by at least five variables, as follows:

1. The luminous intensity of the light.
2. The distance of the light from the observer.
3. The transmissivity of the atmosphere.
4. The brightness, or luminance, of the background.
5. The state of dark adaptation of the observer's eyes.

Every one of these varies without respect to the significance of the signal, as follows:

1. Although no numerical values are at hand, the variation in the normal luminous intensity of brakelights from make to make and model to model appears to be about the same as the average distance between the luminous intensity of the brakelights and taillights used on the same cars. This variation in design is aggravated by differences in transmittance of covers, differences in voltage at the sockets, differences in cleanness, and differences in degree of lamp deterioration.

2. The distance to the signal light affects the apparent intensity in accordance with the inverse square law. But the driver must estimate the distance, which is itself frequently changing, from a combination of binocular stereopsis, chiefly effective at distances less than 100 ft; apparent size, somewhat complicated by variations in actual size; and intervening objects, these, of course, being always in apparent motion and changing.

3. When the air is clear the effect of atmospheric transmissivity is small, but when there is even a little fog in the air this effect may become the most serious one. Atmospheric transmissivity reduces the apparent intensity in accordance with an exponential factor, which frequently becomes so large that even the high intensity of headlights does not make them visible at desirable distances. Nevertheless, when the atmospheric transmissivity drops, a driver soon has no indication of the position and movements of vehicles ahead of him except what he gets from their signal lights.

4. The effect of background brightness, including the influence of other bright lights in the field of view, is a matter on which the psychologists can speak more appropriately than the writer.

5. The state of dark adaptation also is a matter for psychologists to appraise, but if the estimate of absolute intensity varies with these conditions as the minimum perceptible illumination does, the effect may be measured by a factor of 100 or even 1,000.

It would be difficult to find a criterion for differentiating two signals which would be obscured by as many irrelevant conditions as is an intensity difference. It is a dependable signal only if the observer sees the transition in intensity at the instant the brake is applied.

The weakness of the arrangement has evidently been sensed by some designers, because there have been efforts to make a distinction on the basis of color. If a color distinction were well carried out, it would certainly be much more dependable for normal observers than the intensity distinction. Some vehicles, notably busses, have been equipped with red tail lights and yellow brakelights. But this appears to be the reverse of good signal practice, which recognizes yellow as an ordinary warning and red as a signal indicating more than usual danger. At the time when this practice was most common, there was no standardization in the colors used, with the result that every hue from a purplish red to a light yellow was to be seen on the rear of motor vehicles.

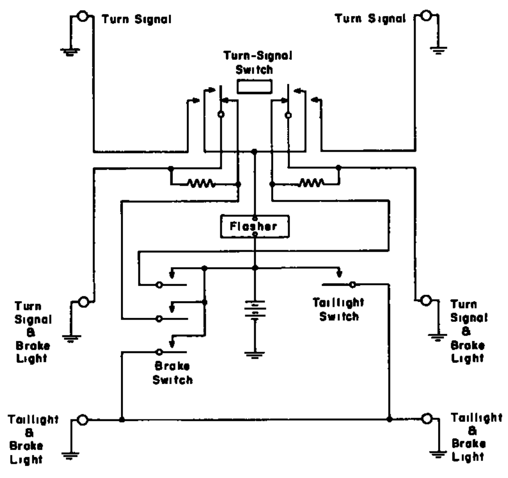

Figure 1. Circuit for vehicle signal lights providing for dual two-light brake signals.

This difficulty could have been corrected by sound standardization of the colors but the red-green confusing protanopes and deuteranopes would still have been able to see only signals of different intensities.

Before the introduction of flashing lights as turn signals it would have seemed practicable to consider a flashing signal as an indication of braking. However, the use of flashing lights for turn signals is now well established. While it is theoretically possible to have two different flash characteristics, it would be necessary to keep them strictly standardized if they were to be sufficiently distinctive for all car operators to recognize at once which signal was being shown.

There remains the possibility of differentiating taillights and brake signals by giving the brake signal a distinctive configuration. The simplest configuration which seems applicable is that of two lights, one directly above the other. If these were placed in the center of the rear of the car with the taillights remaining in their present outboard positions, they would be distinctive both by day and by night. In the daytime the middle position would be evident because the rear of the car would be visible. At night, the complete configuration, including the taillights, would be a flattened diamond-shaped figure with its long axis horizontal.

The central location of the brakelights has, however, the disadvantage that the brake signal is more likely to be obscured by an intervening automobile than it is if the brake signal is given in an outboard position as at present. Moreover, the inclusion of any lights, other than those required for license plate illumination, in the rear center of the car would involve design problems that probably would not be welcomed by those responsible for the appearance of automobiles.

An alternate configuration is a long horizontal rectangle. Such a configuration could readily be made available in some cars by merely including the turn signal lights along with the taillights in the braking signal. To make the two light idea an instinctive one for drivers, it would be desirable to use it by day as well as by night. It also seems desirable to design the system in such a manner that the turn signal and brake signal can be given simultaneously. This can be accomplished by undulating the turn-signal light, instead of completely occulting it, when the brake signal is being given. There is no reason why the lamps and lenses for both these lights cannot be housed, as they sometimes are at present, within a single hood, provided the separation between the two lights is adequate.

The proposed use of a two-light configuration on both sides of the rear of cars and trucks as a brake signal would have an additional merit if the distance between the two lights is standardized. It would give drivers at night one standard distance by which to judge both the distance of the vehicle ahead and its rate of braking. For this reason the vertical separation of the lights should be carefully standardized on the basis of laboratory and road tests. At the same time it would be desirable to include some study to determine the optimum characteristics for the undulating of the turn signal when it is combined with the brake signal.

Figure 1 shows a possible circuit for actuating the rear signals in accordance with this proposal.

Vision at Levels of Night Road Illumination II. Literature 1952-1956

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● CIVILIAN night driving is done within a range of 4 to 0.003 ftL (foot-Lamberts). This range was derived from data available in 1952 (63) and has been accepted by others. Further information available in this field since the earlier report, however, is summarized herein. Another summary by Payrau (60) is of interest and the problems proposed by Bartley (8) as needing study include some pertinent to night driving.

Average road illumination and reflections indicate luminances of 0.018 to 0.35 ftL for asphalt and 0.08 to 3.03 ftL for concrete roads (81). The new Hudson Road illumination is reported within 2.30 and 0.41 ftC on the center line and 0.04 to 0.12 ftC at 100 ft from the luminaire (82). De Boer and Oostrijck (13) discuss a simple measurement for the reflective properties of wet and dry roads, although it is difficult to calculate from their data values appropriate in this country.

Drive-in motion picture screens may have an average luminance of 0.39 ftL (range 0.005 to 1.9 ftL) during projection, and of 0.003 ftL when the projector is not running. During projection the average stray light is about 0.17 ftL (22). The 0.003 ftL is another measure of night brightness without headlamps.

The limit of color vision occurs about 0.037 ftC, according to Middleton and Mayo (51), and 0.012 ftC is needed to distinguish between blue and orange. No evidence was found for the alleged blueness of twilight vision. Hunt (32) reports a gradual decrease in saturation of colors as the adapting light was lowered. At full levels the saturation increased with increasing test color intensity. Dim light to the dark-adapted eye appeared blue rather than colorless. Color seen by the dark-adapted eye is pale blue rather than colorless. Middleton's "Vision through the Atmosphere" (50) should be helpful in evaluating vision out-of-doors. Luminous efficiency varies with intensity for colors in the Purkinje range (61).

Morrison (55) and Holmes (5) object to too bright stop lights. A red light of 50 candles was recommended before the Bristol meeting of the British Association (5) as adequate for a seeing distance of 50 yards against oncoming glare. Stop lights of 100 candlepower give a dazzle out of proportion to the general level of lighting and are said to confuse the following driver rather than aiding him by increasing his confidence.

Motoring at night by civilians is done at photopic and upper mesoptic levels and further study at these levels should aid traffic problems more than at scotopic levels (79). Age lowers the ability to see at night (2).

DARK ADAPTATION

Recent work of Arden and Weale (6) suggests that after 8 to 20 minutes dark adaptation, the integrating power of the retina increases with time, as part of the adaptive process involves change in the size of the receptive field. While this occurred at lower levels than usually found in night driving, a possible nervous function in the retina should be considered.

Dark adaptation varies with individuals and more precise information may be expected from Mote and his assistants (56). Zeidner et al.(80) believe that five minutes is adequate time for dark adaptation to the mesoptic level, which suggests that only a few minutes are necessary to adapt to the higher level at which most driving is done. Dark adaptation varies in accordance with the previous state of adaptation of the eye. Wolf and Zeigler (78) have examined some of the conditions involved in transitions between the scotopic and photopic vision. Preexposure to ultraviolet radiation may raise the threshold of the dark-adapted eye. This increase is scarcely more than normal variation and seems to be a transitory effect but would probably have little effect on night driving.

Further work (5) extending the original investigations of Lythgoe adds information on the effect of surround. Surrounds of 38 degrees and 120 degrees did not have significantly greater effect than a 6 degree field. At all luminances of the central field exceeding 1 ftL, the presence of a luminous surround improved acuity, the optimal effect being observed when the central field and the surround were matched in luminance. Below this level, presumably, the surround should approach but not equal the luminance of the viewed subject. This indicates that only the illuminated road and nearby surround may affect the adaptation of the eye; also that silhouette seeing (pedestrian, etc., darker than the road) common to night driving will be less efficient than viewing an object that is a little brighter than its surround. With such poor visual conditions, brighter clothing, edge road lines, etc., should favor human survival.

Impaired vision has been reported by Landau and Bromberg (40a) in adiposogenital dystrophy, this suggests that the mechanism of scotopic vision may be related to the function of hypothalamus. Another paper (40) indicates further evidence of impairment of scotopic vision from diseases of endocrine origin. They also note variations in dark adaptation during pregnancy, manifested by impairment of scotopic vision from the fourth to seventh months, and showing striking improvement in the eighth and ninth months. Neurotic and psychotic individuals in the 20 to 30 age group had poorer dark adaptation than normal individuals (29). Slight improvement of night vision has been reported from the use of intermedine, a pituitary hormone (49, 60). Recommendations for the control of night driving may some day have to consider potential danger from illness, and such abnormal states may account for some accidents.

GLARE

The effect of glare, or dazzle, is important. With well-spaced traffic the exposure time may be about two seconds (63). Stiles (73) places the level for discomfort glare at 20,000 trolands, which for an average pupil of 2.3 millimeters diameter would be about 1,500 ftL. The effect of glare is that of a veiling luminance on the retina that degrades the contrast of the image and vision. An increase will cause the pupil to close, which reduces the light into the eye and, when not too great, improves the sharpness of vision by reduced aberrations. This reduced illumination of the retina is unfortunate, as it impairs seeing at the edge of the road and other critical low-luminance regions. The expansion of the pupil follows and depends on the amount and time of the glare exposure. Most of the investigation of glare has not directly concerned night driving, but the information should soon be adequate for application to driving (24, 25, 26, 30). Glare measuring equipment has been devised by Fry and Alpern (26) and Jehu (35).

COLORED LIGHT

The use of colored light, or colored glasses, usually decreases vision by about the same amount as the decreased visual transmission of the colored glass. An exception to this statement is Berte's (10) report, showing a small consistent gain in vision, using a Sulzer chart illuminated with yellow light from filters like those used on French automobile lamps. His results are apparently a copy of a table from Monnier and Mouton (54). Since it has not been possible to obtain information on this chart, comment on the results is limited. However, an acuity of 1.00 only occurred at the highest level (about 9 ftC) and it is amazing that with such small differences, the acuities are always just a few units greater in the second decimal place with yellow, than with white illumination.

Miles (52) reported that when clear visibility was 20/32, with yellow it became 20/34, with pink 20/40, and with green 20/46. Combining the pink glasses and a green windshield further reduced vision to 20/60. Amber and green filters decrease visual acuity (9) and while some variation is found when small differences are tested, colored glasses did not improve vision (74). Blackwell (12a) investigated two yellow-tinted night driving glasses and found that these glasses can reduce simulated detection distance by as much as 33 percent as compared with no glasses. Ross (65) reports that using any colored goggle reduces firing accuracy; Malone et al. (46) found yellow less conspicuous than orange for air-sea rescue work. Haber (31) found loss in visibility distance when tinted glasses are worn and that the loss increased with decreasing distance.

A neutral-colored object could be seen at about the same distance with white or yellow light, but Jehu (36) reports that the drivers in the test preferred that their own beams be white. Willis (76), summarizing a British meeting, stated that Grime gave results with white and yellow headlamps, having the same distribution of light, showing that the distance at which an object could be distinguished with yellow was 5 percent greater than with white light. The 20 observers significantly preferred white light without glare. Yellow light was thought to be less glaring at close approach, although a small majority favored white light. (It should be, since the yellow decreases the luminance.) The consensus was that changing to yellow light would not solve the headlight problem. The major fallacies of yellow light have been resummarized by Luckeish (45). Richards (64) tested the effect of yellowness separately from the loss in vision from less light and found yellow poorer at night driving levels of illumination. Miles and Richards work has received favorable editorial consideration (3). Loss of light is more serious at night driving levels, when there is scarcely enough for seeing. When braking distance and visibility distance are the same, a slight decrease in seeing may result in a rear-end collision. While only slight losses in vision have been reported in tests of colored windshields (66, 83), it does amount to driving day and night with colored glasses, and many vision specialists consider any loss dangerous at night.

NIGHT MYOPIA

General agreement has been reached that about 0.50D increased nearsightedness of the eye occurs as the luminance decreases and that this is due to the combination of the Purkinje shift and chromatic aberration. Greater night myopia occurs, but there is no generally accepted explanation for it. Tousey, Koomen, and Seolnik (75) believe that the night myopia can be accounted for by the abberations in the eye. O'Brien (57) accounts for the extra myopia as a result of the zonal aberrations of the eye and the change in the best focus moving towards the lens, together with the structure of the retina. Biessels (11) explains night myopia in that the image curves at the retina for sagital and tangential directions are different. With a large pupil and the greater sensitivity moving from the macula to the periphery, these curves come nearer to the more sensitive region of the retina. He further suggests that it should be called marginal or peripheral myopia rather than night myopia. Knoll (38) has published a review of the literature.

Ivanoff (34) believes that the mechanism of night myopia is largely that of binocular night convergence, which would increase the curvature of the front surface of the lens. Changes in the focus of the lens have been measured by Campbell (17), Campbell and Primrose (18), and Chin and Horn (20) using infrared observation of the Purkinje-Sampson images. Campbell and Primrose conclude that both accommodation and aberrations play about equal part in producing the night myopia. When the eye does not see detail there seems to be a tendency for the lens to focus closer to the eye than infinity. This may be related to the empty field myopia, found at higher illuminations. Chin and Horn do not find that the eye tends to a fixed focus and that the refractive state of the eye can increase, decrease, or remain about the same, as the luminance decreases. The authors object to spectacles with such correction for the Armed Services, because of the difficulty of getting the proper prescription, the fact that they would add to the burden of equipment and bring up the ever present problems of fogging, etc.

Scober (67) recommends increasing the spectacle prescription by -1.00D, or more, for driving after dark and for viewing the motion picture screen. With presbyoptic individuals, he recommends bifocals correcting the distant segment but leaving the lower segment so that they can see the instrument panel. He notes that individuals who are hyperopic (+2.00D) see better at night without glasses. With bluish or white fluorescence the myopia is more at low luminances than with other forms of lighting (68). Rasmussen (62) recommends reducing the hyperopic correction by 0.50D and increasing the myopic correction by -1.25D for night driving and for motion picture viewing. He advises consideration of the activity of the pupil of the eye in connection with the prescription. Wiseman (77) reviews the question of prescribing and concludes "there certainly would appear to be scope for additional research on the subject."

A field test was made by McGuire, Kathan, and Leopold (48). Young soldiers wore negative lenses of varying strengths from -0.5 to -2D and the distance at which they could discover a target was measured. A lens of -1D was superior to plain glass in many cases, but it was impractical to use any general prescription (as -1D) because one-third of the men actually saw less well with, than without it.

There is also a problem involving the changes of the eye in old age and whether or not there is more night myopia than would be expected from the aberrations from increased pupil size and from the Purkinje shift. Until more information is available as to the distribution of night myopia in civilian populations, only a competent eye specialist should prescribe for or experiment with it.

VISUAL ACUITY

Miles (53) and Sloan (71) have reviewed the literature. Gilbert (28) has discussed the definition of visual acuity and Linksz (44) has discussed the standard visual acuity chart. The fine movements and involuntary motions of the eye need to be considered in discussing resolution (21, 62a). Thresholds for acuities are given by Brown et al. (16) and Leibowitz's (43) data on pupil size should be considered. The visibility of road signs has been reported on by Allen and Straub (1) and Case et al. (19). Much work has been done, yet little of it can be applied directly to the problems of night vision.

The importance of contrast and acuity is stressed in Fortuijn's (23) analysis and units for measurement of visual efficiency. Decreasing contrast reduces readability when a flickering light source is used (27).

NIGHT DRIVING VISION

From basic data Jehu (37) has published formulas and tables for calculating seeing distance from the light distribution on the road. Simmons and Finch (70) describe an optical instrument for the measurement of night driving visibility which views an object on the highway and adds enough veiling brightness to determine the threshold. They believe that the most satisfactory way of defining night driving visibility is to relate it to the threshold at which it is just perceivable. Other factors concerned with night driving visibility are discussed, and it is stated that "the roadway situation is one in which relatively large objects (6 min of arc or larger) have to be recognized with certainty in a short period of time (0.2 to 0.02 sec) at relatively low adaptation levels (1 to 0.005 ftL)." Ohara (58) has provided data on the distance at which objects are visible from moving vehicles. His results suggest that acceleration causes reduced visibility at higher speeds. Vibration is a serious factor in limiting vision. The visual loss is greater when the individual is standing on the moving vehicle because of the increase effect of vibration on the eyes. One report (84) indicates more rapid driving at night.

Black (12) discusses problems and methods used in England. Keen vision is required for fast driving, as acuity decreases with speed. He believes the myope is safer, because he is more apt to wear glasses, though truck drivers were found to be exceptions. Keen vision is also required to see the driver who puts out one finger to signal, to be able to see a small hole at a distance, or to perceive a slight change of speed of a car ahead. Illumination on the highway should not change too frequently. At night a myope of 6/18 (20/60) may become 6/36 (20/120) or less. Black is particularly concerned with the dangers of restricted visual fields (tunnel vision).

Some British accident statistics are analyzed by Smeed (72). No correlation was found between accidents and binocular perception and the rate of dark adaptation, but he did find a correlation of more accidents with better roads and vice versa. McGuire (47) reports that the non-accident driver is more mature, more conservative, more intellectual in his interest and tastes, has a higher aspiration level, and is usually a product of a happier family background than the accident-incurring driver.

Lavergne (42) has reviewed various tests used for automobile drivers in Belgium with respect to night vision. Measurement of dark adaptation would be important in critical cases. Ordinarily, only the first ten minutes of dark adaptation would need to be measured. Acuity and peripheral vision also are important for night driving, although no tests are described for them. Fatigue and the possible advantages of using simple threshold tests are discussed by Ibbs (33).

An interesting experiment is reported by Brier (14) who made himself deficient in vision from 6/5 to 3/60 (20/15 to 20/400) by wearing +6.00 spheres. A number of trips were made and he found that after five minutes he had no great difficulty, even when driving at fairly high speed. His general impression was like that of driving through a light fog and no further precautions were required than would be necessary for such conditions. At night he had to lower his speed to about 25 mph. Headlights were reported less troublesome, but it was difficult to see pedestrians, bicyclists, and road obstructions. It is Brier's opinion that a visual acuity of 3/60 (20/400) is adequate for day, and at reduced speed for night. The loss of one eye is of little importance in driving and he reports that several of his patients with acuities of 3/60 drive, although one preferred his glasses when driving at night. Road signs should be made larger and easier to read for those with poor acuity. Brier's views are summarized by stating that "in short we should aim at minimum restrictions and a better appreciation of accident psychology in common sense approach to this question."

A few years ago there were a number of letters to the editor in the British Medical Journal discussing what visual acuity is important for driving and the fact that many drivers (especially truck drivers) will not wear glasses, yet have no accidents although some drive with poor vision.

A change of prescription may lead to difficulty in driving. Such a case is reported by Morrison (55): "The patient stated that the glasses were quite comfortable but when driving he experienced difficulty in keeping his vehicle in the correct part of the road, a symptom typical of aniseikonia." The patient had reported because he had had a minor collision.

Corrected myopes, according to Ames (55), tend to locate objects more distantly than corrected hyperopes. Newly corrected nearsighted people may brake too quickly and farsighted people may brake too slowly, both when first corrected, or while getting used to a change in spectacles. Space perception abnormalities or distortions tend to increase with motion. Although it appears possible to adapt to changes in aneisikonia, compensation may not occur. Morrison (55) considers that night driving is more dependent on stereopsis because there are fewer visual clues. Impaired space perception, such as aniseikonia, could then control the motorist's actions, much as the normal person does not respond to an added size correction lens in familiar space, but loses orientation without familiar clues (as a "leaf room") and sees a markedly distorted world. This change and possible disorientation of space at night could contribute to accidents and Morrison urges that motorists be screened for aniseikonia. He also recommends that motorists do not drive until ten days after they receive their first spectacles.

Only those with corrected aniseikonia will appreciate the comments in the preceding paragraph. Some have experienced the improvement of driving from better seeing. There is little point to expecting space perception problems to clarify all driving accidents. Nevertheless, vision specialists should consider whether glasses or a change in prescription will disturb the user's space orientation sufficiently to endanger himself or others, should he drive with them before becoming used to them, and be responsible for advising their patient on proper use when necessary.

Drug effects can be of importance in driving. No success with drugs for general aid in dark adaptation has been reported. Atropin causes objects to recede. Alcohol is reported to increase esophoria or decrease exophoria, producing a tendency to drive in the center of the road (55).

There has been much discussion of the requirements and tests for driver's licenses (4, 59). Lauer (41) condemns many of the present practices and warns optometrists that if there is not some improvement, the visual examining program may fail. Sherman (69) advises eye specialists that there is a rich field in training people on how to see. The general problems of the role of vision in motor vehicle operations have been discussed by Brody (15). A modified program in use in Kentucky is described by Oldam et al. (59) and Bannon has described the studies carried out in North Carolina (7).

There seems to be no question but that poor vision does contribute to accidents during night driving, although exactly what deficiencies contribute most, or how, remains to be determined.

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Principles and Figures of Merit for Roadway Lighting As An Aid to Night Motor Vehicle Transportation

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● FIGURE of merit ratings for the seeing and traffic effectiveness of roadway lighting is an obligation which has received greatly increased attention during the past year. Numerical ratings will provide a simplified basis for progress in the essential night use of street and highway facilities for motor vehicle transportation.

Organized programs for the investigation and assessment of roadway lighting benefit are underway by groups such as the Illuminating Engineering Research Institute, its Technical Advisory Committee on Light and Vision, several universities, and the I. E. S. Sub-Committee on Roadway Lighting Principles. Other organizations are now formulating plans for participation, on the urgently accelerated action basis which the night traffic problem warrants.

Technical interest results from realization of the opportunity to make an outstanding contribution to the public welfare.

ACCOUNTABILITY FOR ACTION

Accountability and responsibility to the public is in the capable hands of engineers and officials employed by governmental agencies and numerous other organizations or associations. Their success in providing efficient, pleasant, and attractive night driving conditions will be aided by figure of merit ratings for the seeing and traffic benefit of roadway lighting. Recognition and knowledge of its benefits will determine the type of lighting and the extent of its use to improve night driving conditions.

The I. E. R. I. Technical Advisory Committee on Light and Vision has pointed out that assessment of lighting effectiveness should determine how much better several types of good roadway are as compared with poor lighting, or as compared with conditions when no roadway lighting is provided (Fig. 1).

Such comparative ratings will be in terms of seeing factor benefit and benefit in the operation of night traffic. Seeing factor ratings are basic. For example, a certain amount of traffic benefit is produced by improvement of seeing to a specified number rating. Increasing the seeing rating by further improvement of the lighting will usually increase the numerical traffic benefit rating.

MULTI-BILLION DOLLAR NIGHT TRANSPORTATION BUSINESS

The general objective of roadway lighting is to provide night seeing for desireable driver environment, attitude, performance, and night use of motor vehicle transportation facilities.

In comfort, convenience, and safety, the night traffic objectives of roadway lighting are similar to those which provide the background for other work being done in highway and traffic engineering, in street and highway construction and modernization, and in automobile design and development.

The multi-billion dollar motor vehicle transportation business must be kept open after dark. That is an obvious economic and social necessity. Success in this business involves at least some roadway lighting of a type which will produce really good seeing conditions.

NIGHT TRANSPORTATION ESSENTIAL FOR NIGHT LIVING

Many more people could use the roadways at night if conditions are improved for seeing and for night living with motor vehicle transportation.

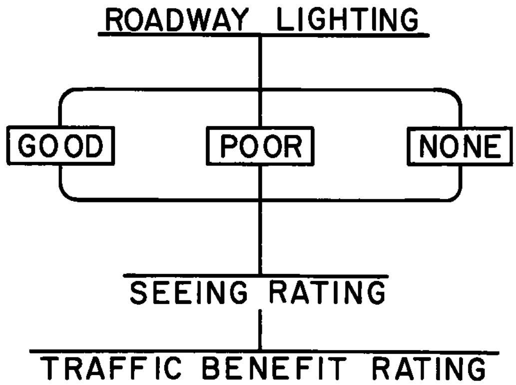


Figure 1. General basis for assessment of roadway lighting effectiveness.

Night living takes on new and even greater significance when future night traffic conditions are anticipated. Traffic engineers predict that motor vehicle traffic will increase by one-third by 1965 and double in volume by 1975. The seeing comfort, convenience, and accident prevention value of roadway lighting influences the night use of the multi-billion dollar investment in streets, highways, autos, trucks, and buses. The value of this investment depends upon the night usefulness desired by the people; for instance, an automobile is of small social or economic value standing in a garage.

For existing roadway systems and new streets and highways now in the planning stage it is vital that careful studies be made for improving night seeing conditions. Obviously, the human desire and efficiency of the drivers is a basic consideration for progress. Figure 2 diagrams the basic interrelations.

COMFORT FOR NIGHT TRAFFIC

The traffic objectives of roadway lighting are shown in Figure 3. These are similar to objectives of street and highway construction for daytime use; that is, comfort, convenience, and safety.

Traffic comfort is the comfort people like and enjoy—which the Virginia Department of Highways features on its detour signs, which say: "This construction is for your future comfort and safety. Drive Carefully." This is the comfort objective which sells automobiles and smooth, pleasant, and attractive streets and highways. It must be an important objective in the use and choice of roadway lighting.

The comfort quality of driver seeing deserves greatly increased attention. The phychological and physiological condition of the driver is involved.

The necessary seeing depends upon the more obvious adverse factors, such as fatigue, monotony, carelessness, driver vision, concentration, attention, judgment, driver reaction, and even intoxication. Poor seeing may induce and accentuate the effect of these and other adverse factors.

Good seeing generally alleviates such conditions, making night driving easier, less tense, more pleasant and attractive, with greater freedom from fear or annoyance. Some safety factor in comfort should be provided. Comfort is one of the principal night-driving objectives. In many instances it applies to the pedestrian as well as the driver.

DRIVER ALERTNESS

Favorable comfort conditions for night driving may lessen the extent and effect of driver alertness factors such as fatigue, hence improve visibility conditions.

CONVENIENCE

Quality of traffic flow is another traffic benefit of roadway lighting. Good seeing may expedite traffic and help relieve congestion. Roadway lighting generally makes possible higher safe or "critical" vehicle operating speeds during night hours. These speeds may be 10 to 20 mph higher than

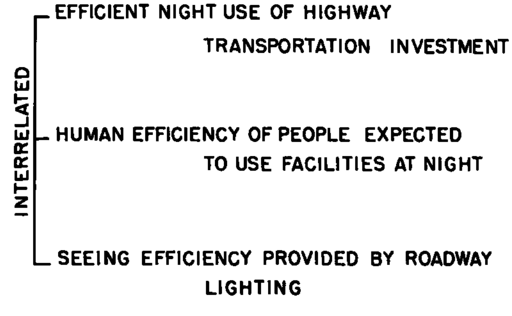


Figure 2. Basic interrelations in night roadway lighting.

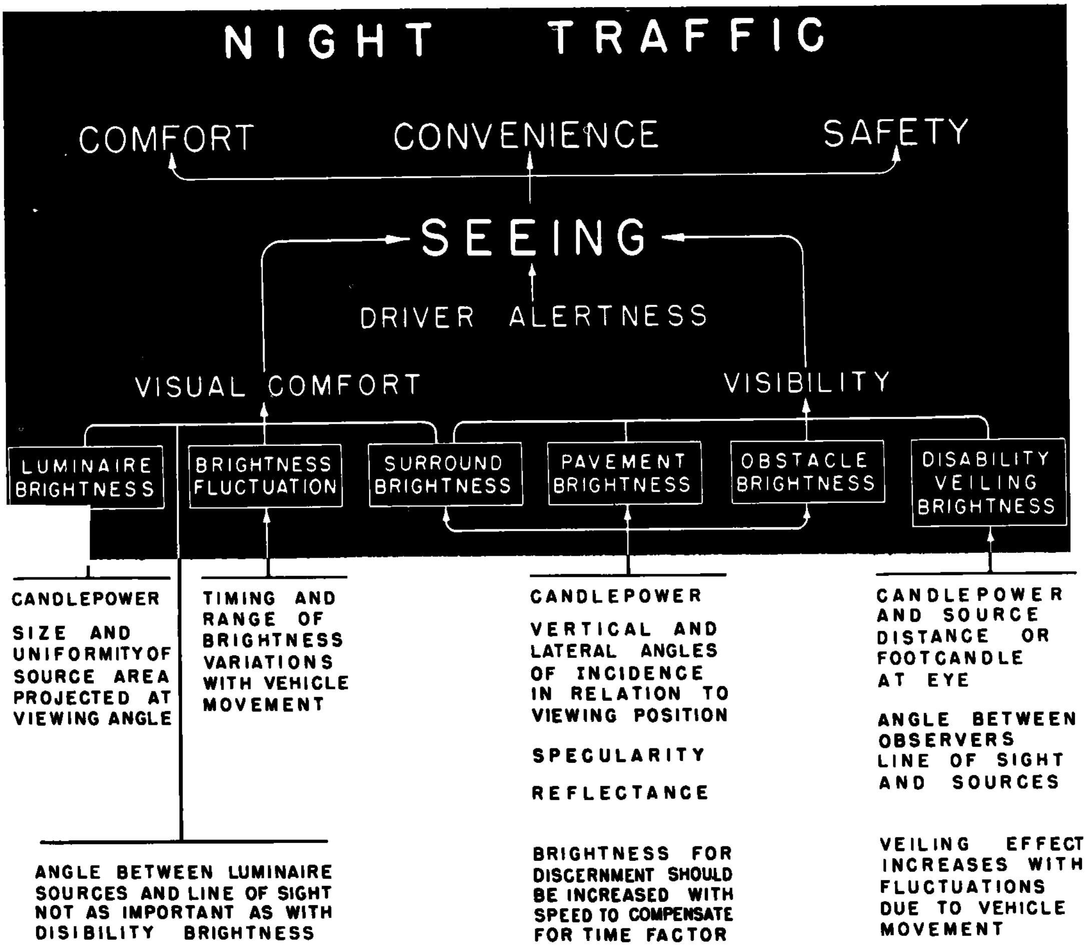


Figure 3. Traffic objectives of roadway lighting.

the speeds which might be safe when seeing conditions are poor. The economic value of the time thus saved may be many thousands of dollars per mile of roadway per year.

When designed for good seeing, roadway lighting will encourage and increase night use of the roadway system, distributing a portion of the traffic loads to the night hours. Those who use the streets and highways at night generate motor fuel tax revenue.

Proper vehicle headways, spacing, use of full pavement width and proper lanes, acceptance of available passing opportunities, are some of the operational and capacity benefits. A lighted roadway background or "vehicle-path" aids judgment of speed and direction of vehicles. It also tends to minimize any adverse effect of bright lights in the field of view.

TRAFFIC SAFETY

Roadway lighting aids law enforcement. It is also very convenient for those who might otherwise be timid about flat tires, on-the-journey trouble, or nocturnal crime.

The traffic safety benefits of good seeing are generally well known. The prevention of night accidents involves seeing the situation soon enough and far enough in advance to avoid collision. This sight distance at night generally involves visibility safety factors of brightness or brightness contrasts which are sufficient for quick and certain discernment. Knowing the route or vehicle path ahead (the roadway contour and alignment) often makes the difference between a hazardous or safe condition for the driver and the "other fellow," whether he be driver or pedestrian.

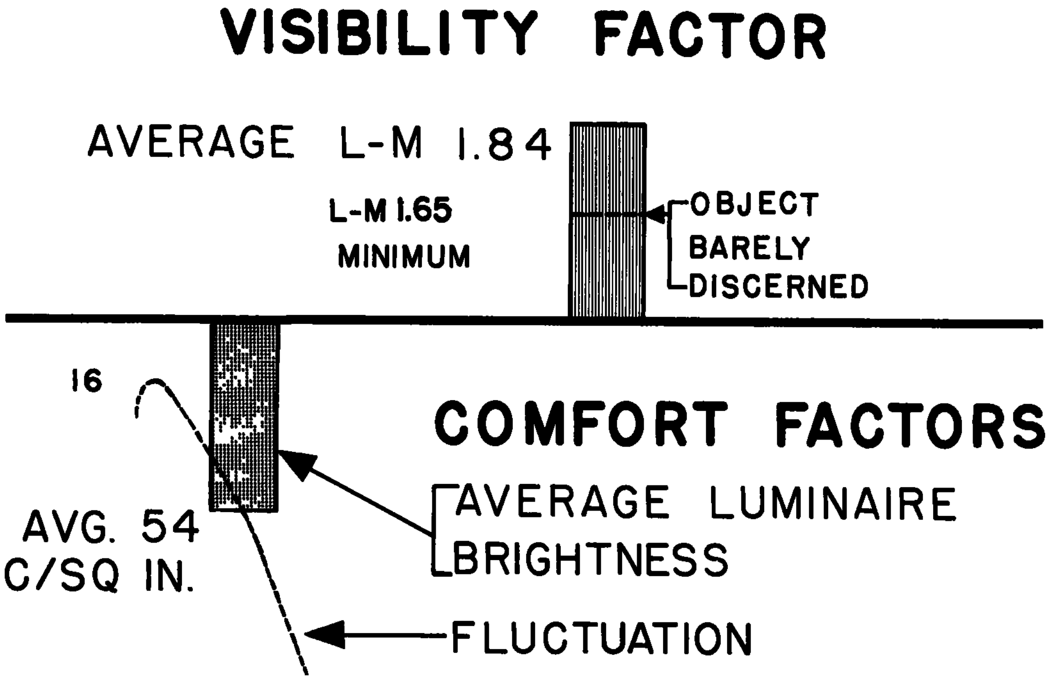


Figure 4. Calculated seeing factor ratings.

EVALUATION MAY BE THE PROBLEM

Evaluation of traffic and seeing benefit of roadway lighting, including the relative importance of seeing comfort and visibility, should also obviously involve many highway traffic engineers. The public, those responsible for the installation and operation of roadway lighting, and those responsible for the successful night operation of motor vehicle transportation systems, are interested participants.

Rating is a big job, even when all concerned are participating, including those who represent various segments of the nation's 70 million drivers.

VISUAL FACTORS IN SEEING

Performance data pertaining directly to the seeing objectives of roadway lighting systems can be presented using the outline shown in the mid-portion of Figure 3. Visual comfort, driver alertness, and visibility data should have a common basis consistent with the roadway, its lighting, the vehicle, and the driver. Many of these factors are interdependent.

An over-all numerical rating combining several seeing factors may materialize based on understanding of objectives and assumed conditions.

CALCULATED RATINGS BASED ON BEST AVAILABLE DATA

Certain of the factors in seeing under roadway lighting may be calculated using the data available. Such calculated ratings are shown in Figure 4.

The calculation method now being used was described before the 1955 I. E. S. National Technical Conference in the paper "Luminaire Light Distribution Principles." This paper was published in Illuminating Engineering (December 1955).

The calculated seeing factor ratings also were described in a paper "Improving Seeing Efficiency with Roadway Lighting" published in the August 1956 issue of Traffic Engineering.

Pavement brightness visibility data for the foregoing papers are based on studies presented in a paper by Reid and Chanon, entitled "Evaluation of Street Lighting" (Illuminating Engineering, 1939).

The I. E. S. Sub-Committee on Roadway Lighting Principles is currently using the evolved method of rating seeing factors averaged and shown in Figure 4. This subcommittee and the I. E. S. Committee on Street and Highway Lighting are sponsoring studies on discomfort glare under roadway lighting conditions. The work of Putnam and associates at Case Institute has progressed considerably during the summer of 1956 under a new grant sponsored by the Illuminating Engineering Research Institute.

Data for rating typical roadway lighting discomfort conditions in ratio to B. C. D. (borderline between comfort and discomfort) should be available soon. These data will help correlate the combined luminaire brightness ratings, now shown in Figures 4 and 5, with luminaire size in visual angle, surround brightness, and viewing angle. Comfort sensation ratings then will be expressed in discomfort ratio to B. C. D. This ratio to B. C. D. will be combined for each driver position (Fig. 5) and longitudinally averaged for the representative roadway lighting system as now shown as average luminaire brightness in Figure 4.

RATINGS FOR SIMPLIFICATION

Seeing factor ratings for representative roadway lighting systems will at least simplify to numbers similar to those shown in Figure 4.

The rating may be in terms of:

1. Relative visibility (a) Average (b) Minimum.
2. Relative comfort sensation (a) Average (b) Fluctuation range and time.

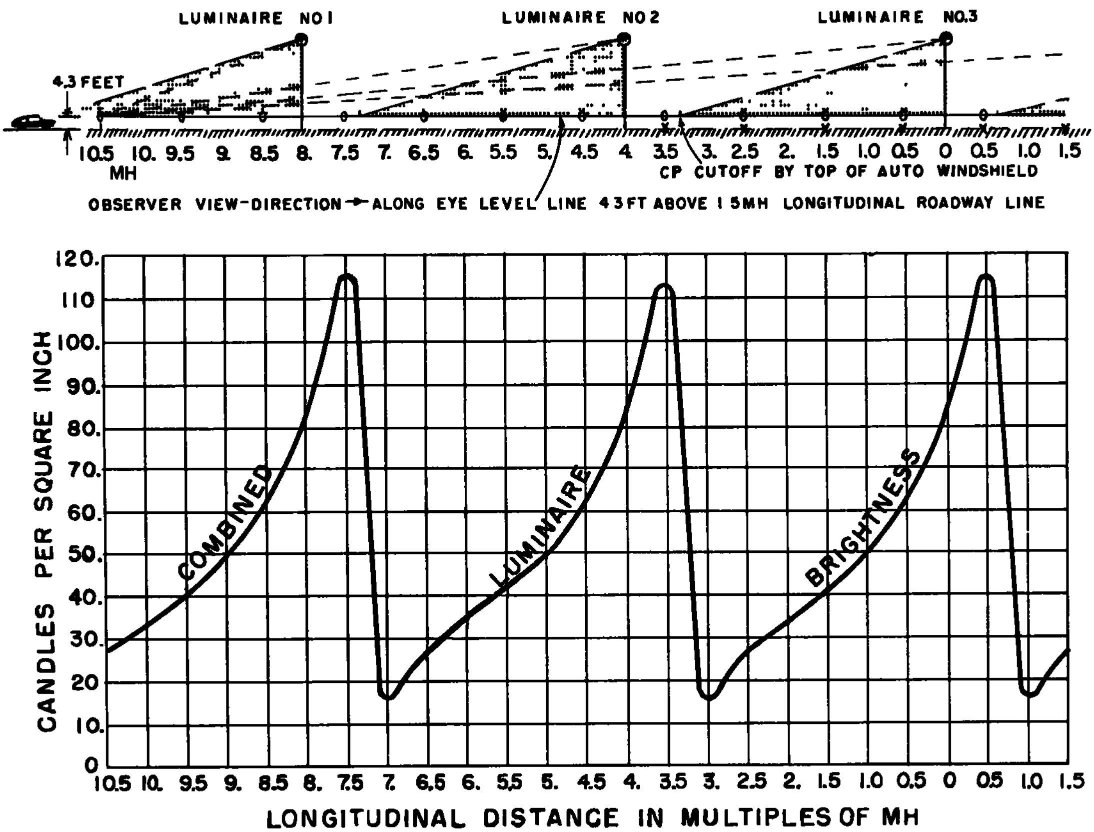


Figure 5. Rating seeing comfort factors involves the dynamic effect of fluctuation in combined brightness of luminaires in the driver's eyes as he proceeds.

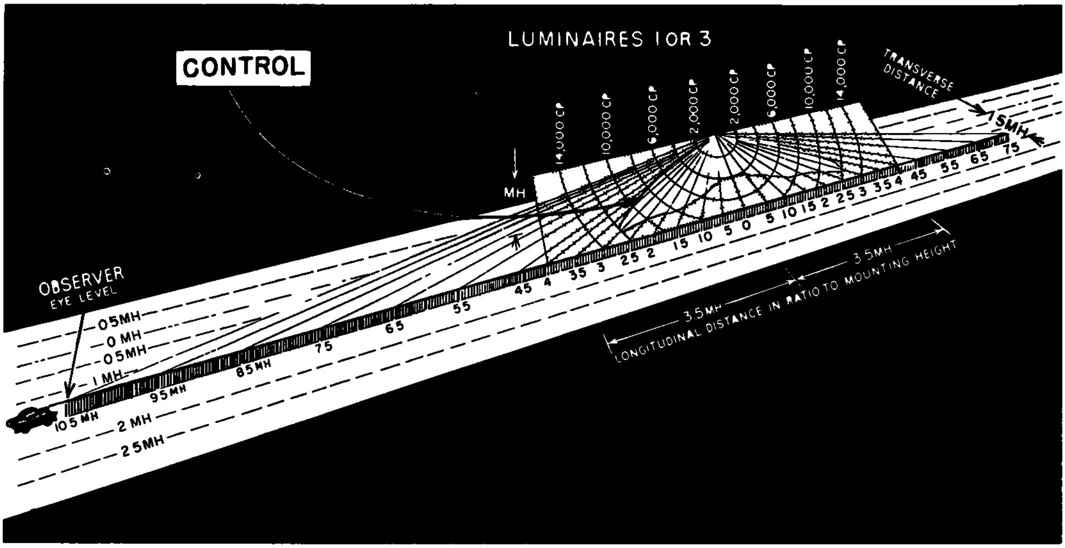


Figure 6. Control and diminution of luminaire candlepower at high angles is shown by new inclined plane type light distribution curves. Perspective diagram shows control of candlepower distributed along a representative driver-observer eye-level line at 1.5 MH (or 45-ft) transverse distance from the luminaire. Such candlepower control restricts the luminaire brightness factor in discomfort (Fig. 5) and loss of visibility due to disability veiling brightness (Fig. 8). Generally the candlepower distribution is restricted at longitudinal distances from the luminaire greater than the 3.3 MH top-of-auto-windshield cutoff.

VISIBILITY RATING

In this instance the average relative visibility to the scale of the Low-Range Luckiesh-Moss Visibility Meter is 1.84.

The 1.64 minimum relative visibility may be more significant. How much better does the visibility rating have to be to assure adequate tolerance or safety factors for conditions such as typically tired drivers and high speeds. The Luckiesh-Moss Low-Range Visibility Meter used in the visibility studies by Reid and Chanon was the basis for the following definition:

"A visibility of 1 (as applied to seeing for safety on streets) is defined as mere discernment of a one-foot obstacle of zero brightness on a background having a substantially uniform brightness of approximately 0.01 footlambert, by a stationary observer with normal vision, standing 200 feet away, at fixed attention, with no source of direct glare in the field of view."

VISUAL COMFORT RATING

For comparison with the plus visibility factor, relative comfort sensation rating will be provided. This rating will be based on representative systems. It probably will be given in ratio to B. C. D., in accordance with the data being established by the Putnam studies at Case Institute.

In the interim, Figures 4 and 5 present luminaire brightness, one of the principal negative factors in roadway lighting. The longitudinal average combined luminaire brightness from the system in the drivers view is about 54 candles per square inch.

Figure 5 shows the dynamic effect of fluctuation in the combined brightness from several luminaires in the drivers field of view as he travels, from left to right, along a representative roadway path. The brightness varies from 16 to 116 or in a ratio of more than 7:1. The "flicker," or fluctuation ratio, is 7.25 to 1. The 116-candle-per-square-inch maximum may be most significant. The brightness peaks successively at

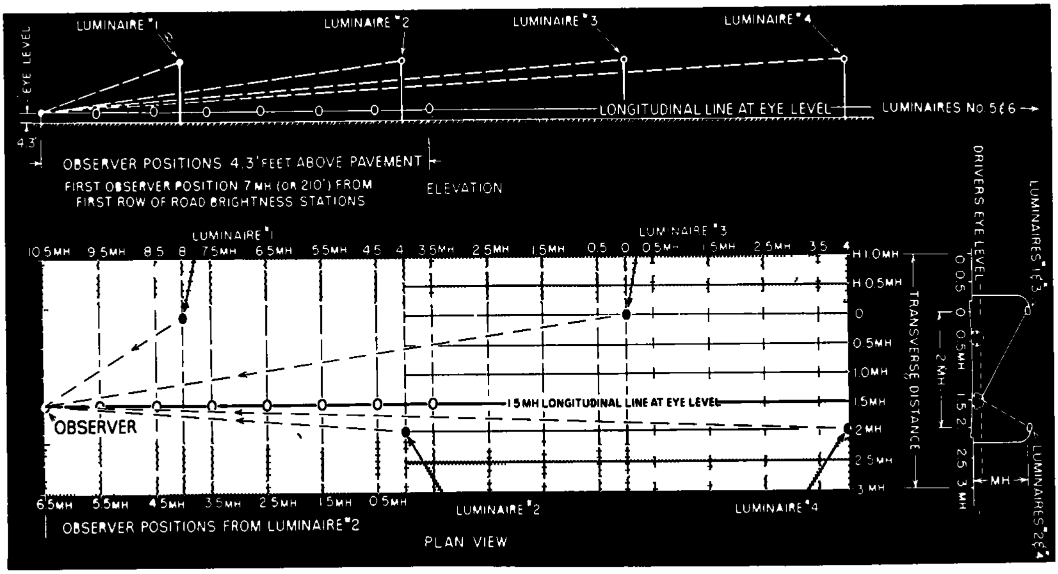


Figure 7. Representative roadway lighting layout showing the series of driver-observer viewing positions along the longitudinal eye-level line 4.3 ft above the pavement and at transverse distance of 1.5 MH (45 ft) with respect to luminaires on the driver's left, such as No. 3. This eye-level line is also at 0.5 MH (15 ft transverse distance) with respect to luminaires on the driver's right, such as No. 2 and No. 4. The combined discomfort and disability effect of several luminaires is calculated for each of the series of driver observer positions.

intervals of 2 sec for a driver traveling at about 40 mph along the roadway lighting system assumed to be representative.

Figure 5 includes the brightness of luminaires at distances including 10.5 MH, generally about 315 ft. The luminaire brightness data assume that the projected area of the luminaire light sources is constant at 100 sq in.

It should be borne in mind that the relative comfort sensation or discomfort ratios should be compared with the visibility which the roadway lighting system provides. There is more over-all comfort driving along a well-lighted roadway than on a roadway having no lighting at all to produce visual discomfort from the luminaires.

RATINGS MAY BE COMPARED WITH DESIRE

The foregoing describes the type of ratings to be furnished for user guidance. Ratings desired may be compared with ratings obtained with the representative types of lighting systems. Such ratings may also be compared with the desire and preferences of those who use the roadways at night. These results also may be compared with the effectiveness of the roadway lighting system in producing the traffic comfort, convenience, and safety objectives.

Visibility and the relative comfort sensation produced by luminaires in the field of view can be seen and appreciated. The following pertains to the new methods of presenting and using data on the factors shown in the lower portion of Figure 3.

CONTROL OF CANDLEPOWER ALONG EYE-LEVEL LINE

Figure 6 shows the new inclined plane method of presenting the luminaire candlepower distribution along the representative driver eye-level line. The candlepower is controlled and diminished at high angles extending to distances from the luminaire greater than the 3.3 MH distance at which the top of the typical auto windshield cuts off the light from the luminaire.

Inclined-plane candlepower curves really show the desirable light control for seeing:

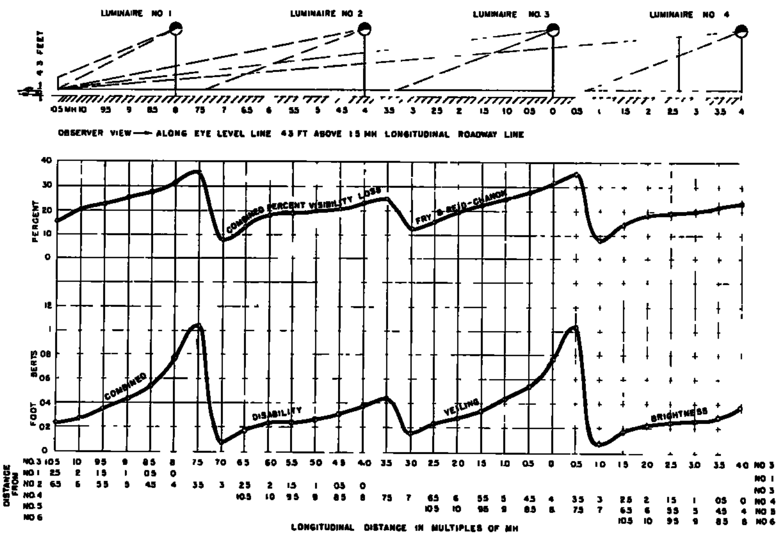


Figure 8. The combined percent loss in visibility due to disability veiling brightness varies with the dynamic driver-observer movement along the roadway, control of combined luminaire candlepower, viewing angle and distance from each luminaire, and the top-of-auto-windshield cutoff.

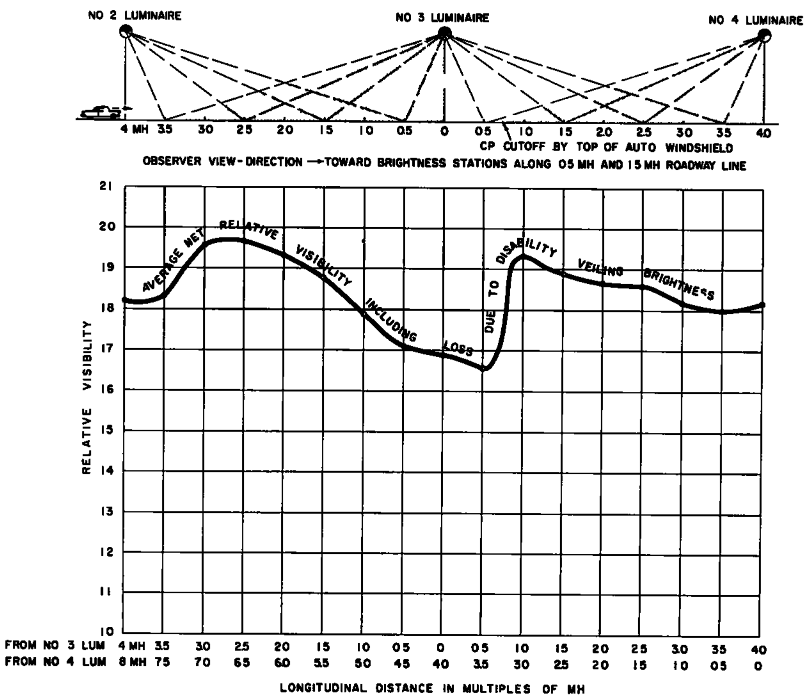


Figure 9. Variation of combined net relative visibility produced by the lighting system with driver viewing position.

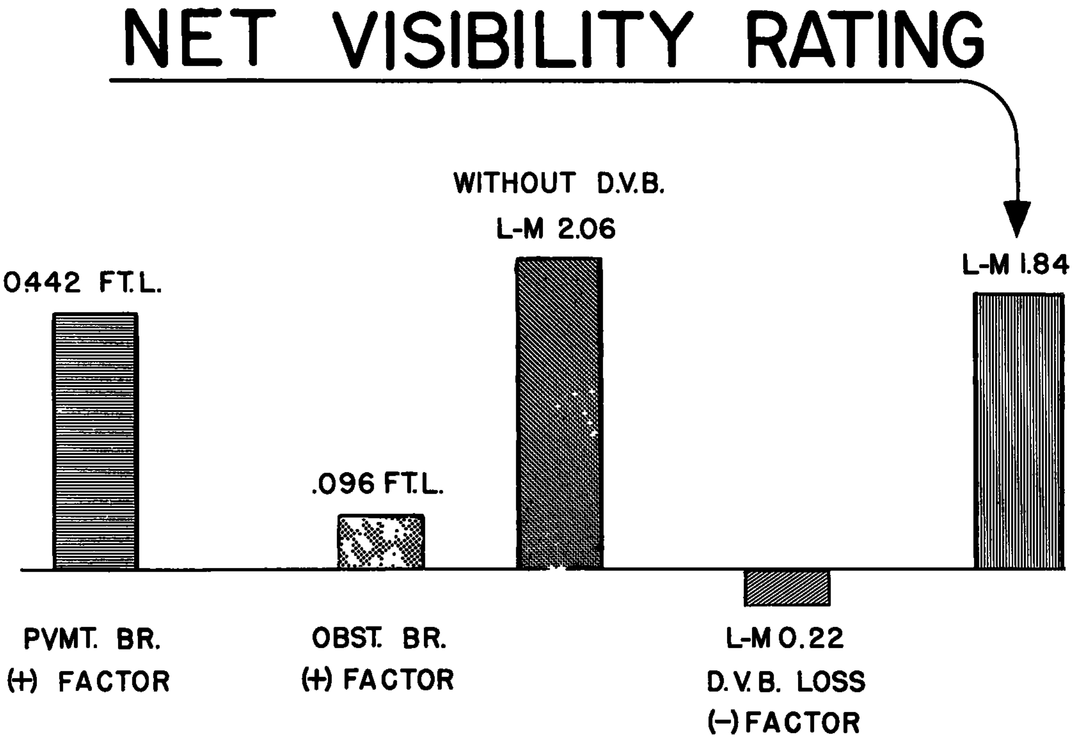


Figure 10. Pavement brightness is a principal plus factor in visibility.

that is, control of (a) luminaire brightness, a principal factor in discomfort sensation; and (b) percent loss in visibility due to D. V. B. (disability veiling brightness).

To show this control of candlepower, representative and uniformly spaced driver eye-level positions are designated along longitudinal roadway lines. The inclined planes and radial lines extend from the luminaire light center down to the eye-level positions. The relative candlepower toward eye-level positions shows the control.

Eye-level candlepower data such as these have not previously been generally available.

REPRESENTATIVE ROADWAY LAYOUT FOR EYE-LEVEL CANDLEPOWER

The candlepower to eye-level data shown in Figure 6 pertain to the luminaires to the left of the driver-observer's path (Fig. 7). As the latter shows, another set of luminaire candlepower data is required for the effect of luminaires at the driver's right. The combined discomfort and disability effect of several luminaires is calculated for each of the dynamic series of driver-observer positions.

DISABILITY VEILING BRIGHTNESS

As the driver proceeds along the roadway the combined percent loss in visibility due to disability veiling brightness varies with driver-observer movement along the roadway (Fig. 8). The fluctuation is due to control of luminaire candlepower, viewing distance from each luminaire, viewing angle, and the top-of-auto-windshield cutoff. The longitudinal average loss in visibility is 21. 5 percent. The maximum-to-average ratio is 1. 67 to 1. The maximum loss occurs when the driver-observer is approaching luminaires on his right, such as No. 2 or No. 4, just prior to top-of-auto-windshield cutoff. The percent loss is for a driver traveling 25 to 40 mph (by Reid-Chanon data). The indications were that the fluctuations cause slightly greater visibility losses at higher speeds.

RELATIVE VISIBILITY VARIES ALONG ROADWAY

The combined net relative visibility produced by the lighting system varies with driver viewing position (Fig. 9). Note the correlation between minimum visibility roadway distance stations and the driver-observer position for maximum loss due to disability veiling brightness (Fig. 8).

The plus visibility is produced by the brightness contrast of targets against a series of roadway stations at 7-MH viewing distance from the driver. Visibility at each roadway station distance is the transverse average of relative visibility at locations along the two representative roadway lines (0.5 MH and 1.5 MH). The relative visibility rating for the lighting system is a longitudinal average of 1.84. The ratio of average to minimum visibility is 1.11 to 1.

AVERAGE BRIGHTNESS FOR THREE FACTORS

Longitudinal average figures for each of three factors resulting in a net relative visibility rating for a representative roadway lighting system are shown in Figure 10. The transverse average of the pavement brightness and that for obstacle brightness are actually combined at each station for visibility at each station, then reduced by the

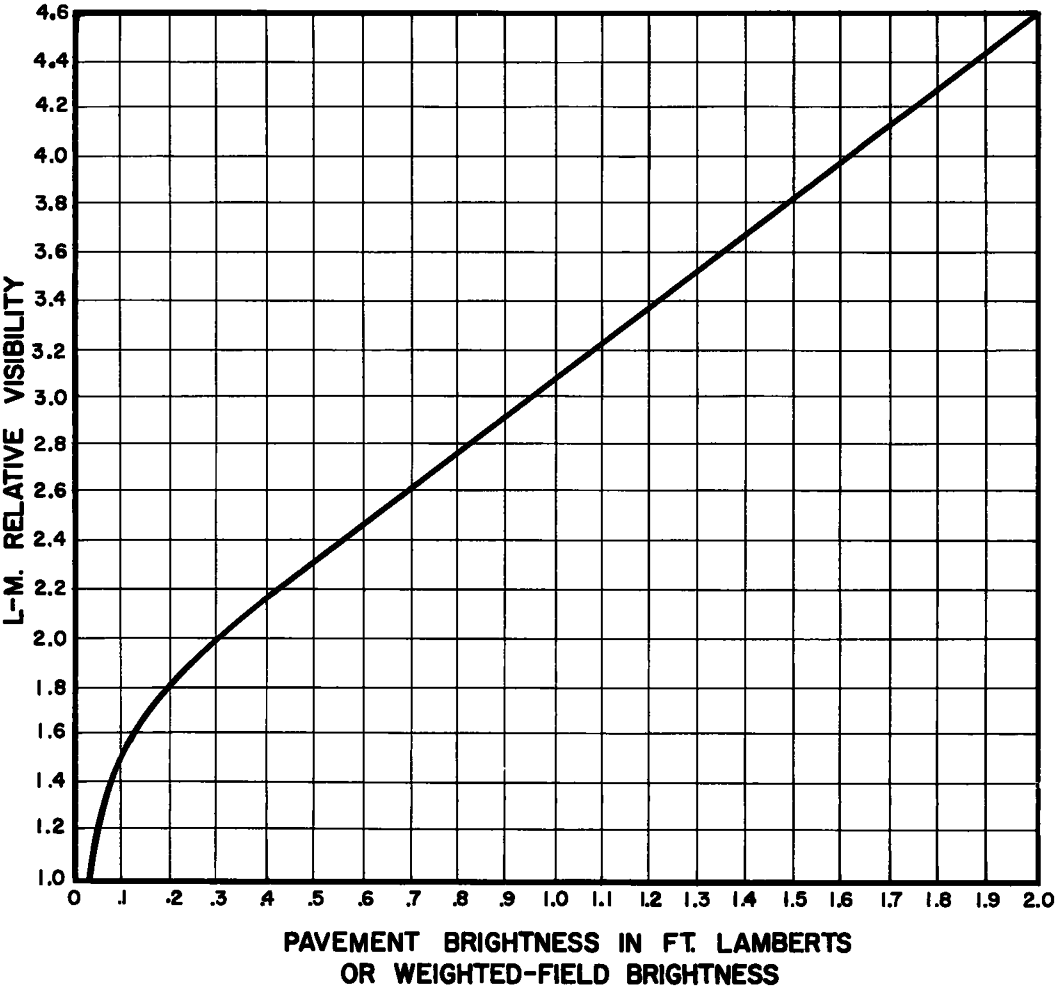
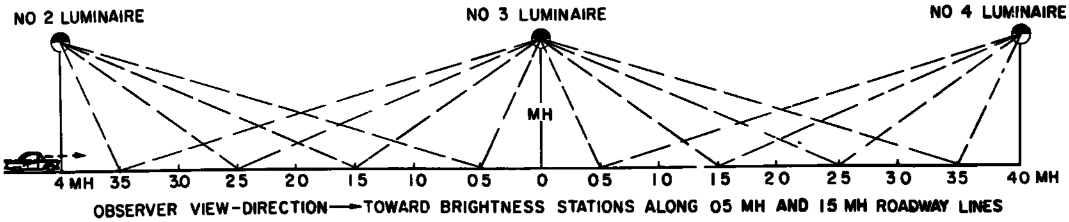


Figure 11. Relative visibility rating produced by pavement brightness or weighted field brightness.



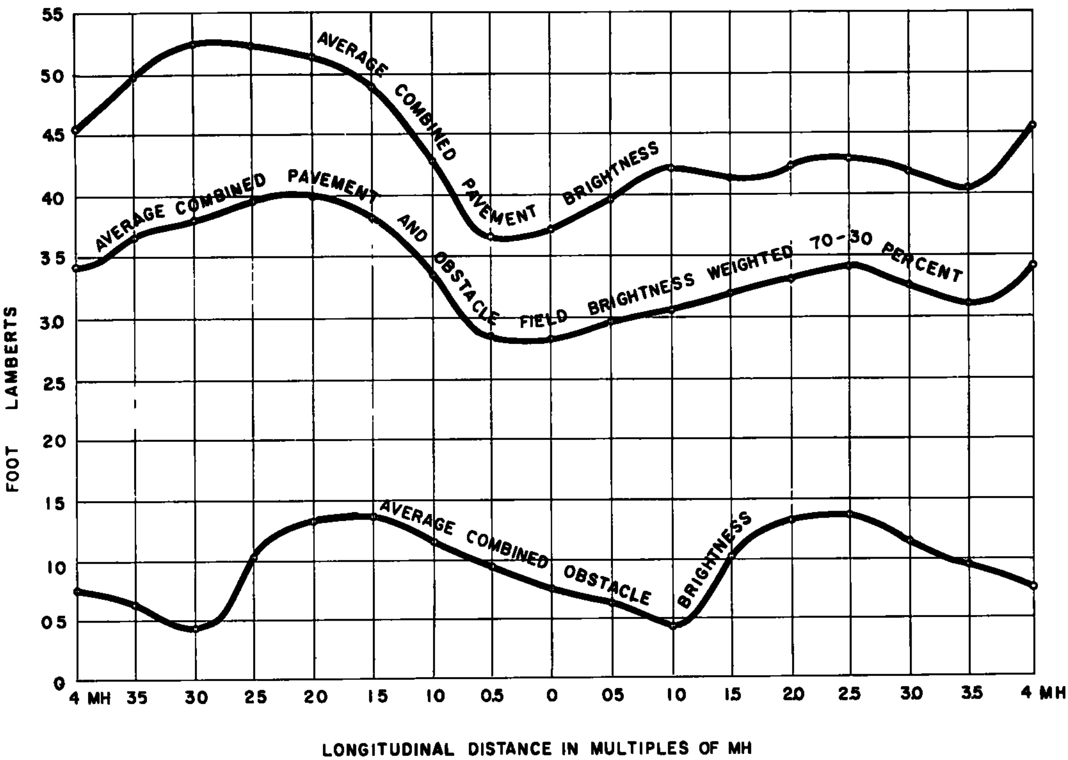


Figure 12. Variation of average combined pavement brightness, average combined obstacle brightness, and field brightness.

percent loss in visibility at each station due to D. V. B. As shown by Figure 10, pavement brightness is one of the principal plus factors in visibility.

RELATIVE VISIBILITY INCREASE WITH PAVEMENT BRIGHTNESS

The relative visibility rating produced by pavement brightness, or weighted field brightness, is shown in Figure 11. The weighted field brightness, for example, may consist of pavement brightness and obstacle brightness, weighted 70 and 30 percent, respectively. The relative visibility is as measured and in accordance with the scale of the Luckiesh-Moss Low-Range Visibility Meter. The field and laboratory correlation of relative visibility with pavement or field brightness is as described by Reid and Chanon.

PAVEMENT AND OBSTACLE BRIGHTNESS

Figure 12 shows variation in the average combined pavement brightness, the average combined obstacle brightness, and the field brightness. At each longitudinal distance the brightness at stations along the 0.5-MH and 1.5-MH roadway lines are averaged transversely. The field brightness at each station is weighted 70 percent pavement brightness plus 30 percent obstacle brightness. Longitudinally the pavement brightness averages 0.442 ftL (see Fig. 10).

The combined pavement brightness (Fig. 12) is based on Reid-Chanon brightness data rearranged for the 0.5-MH and 1.5-MH roadway lines. The pavement brightness data are for asphalt. The sample tested had been in service for eight years. The over-all reflectance was 8 percent.

The combined obstacle brightness for stations along the two roadway lines is based on an obstacle or target having a diffuse reflectance of 8 percent. The longitudinal average obstacle brightness for the system is 0.096 ftL. The ratio of average-to-minimum obstacle brightness is 2.2.

The transverse average of brightness at two pavement stations along the 0.5-MH and 1.5-MH roadway lines is combined with the obstacle brightness at the two target locations at longitudinal distance 1-MH closer to the observer.

One of the variables in seeing rating is the range of light reflection or brightness from the pavement surface. Modern roadway lighting uses special design techniques to produce good seeing with typical traffic-used pavement surfaces. However, some improvement in seeing usually may be obtained by special treatment of the pavement surface for favorable light reflection characteristics.

INCLINED PLANE CANDLEPOWER TO PAVEMENT LEVEL

The new inclined plane candlepower curves provide data extending to pavement level (Fig. 13). This shows the plus factor build-up and proportioning of luminaire candlepower for visibility along the 1.5-MH longitudinal roadway line. From specified driver-observer viewing position distances, variations in pavement brightness and obstacle brightness from specific surfaces will be proportional to variations in candlepower. The brightness resulting from several candlepower distributions, such as this along two roadway lines, are combined (Fig. 14) to represent a system of several luminaires.

Such new inclined plane candlepower distribution curves, which provide the essential

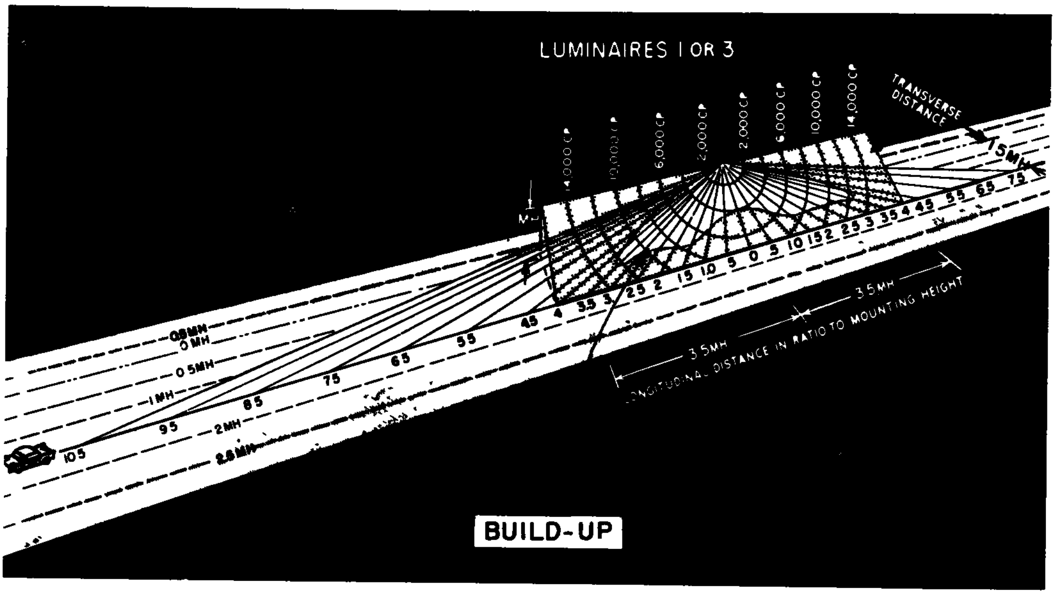


Figure 13. Plus factor build-up and proportioning of luminaire candlepower for visibility along 1.5 MH longitudinal roadway line, as shown in new inclined plane light distribution curves.

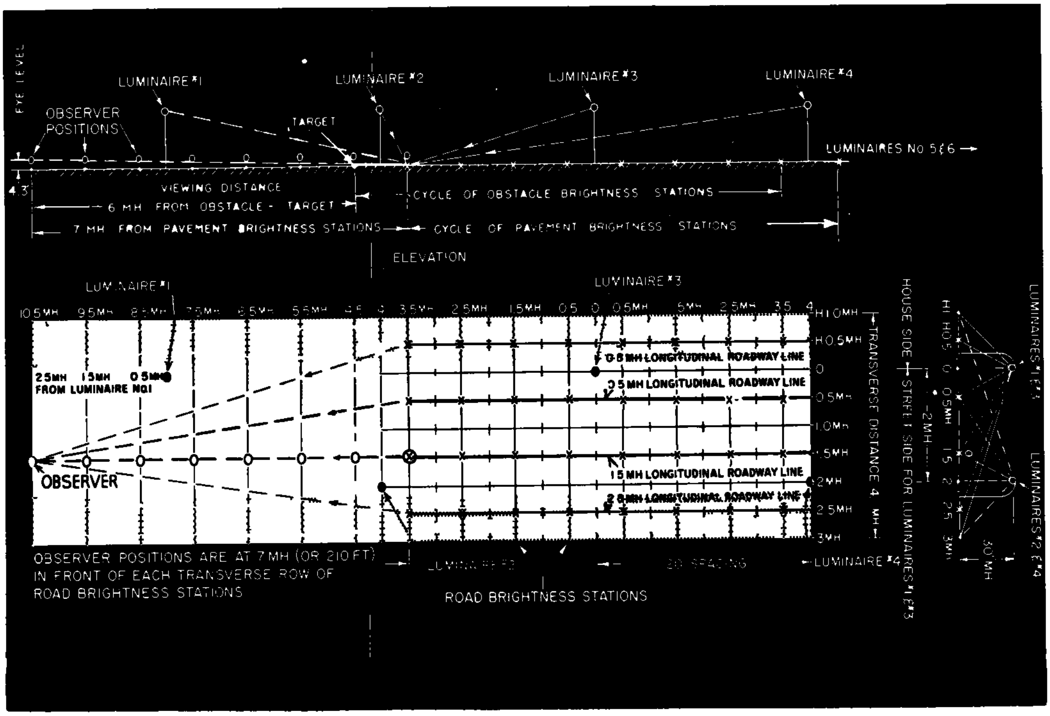


Figure 14. Representative roadway and lighting layout and conditions for calculation of relative visibility.

luminaire performance data, have long been needed to show the buildup of pavement level candlepower for both pavement brightness and obstacle brightness producing visibility. This is shown by the proportioning of candlepower in the inclined plane extending from the luminaire light center down to representative, uniformly spaced, pavement level stations. The pavement brightness or obstacle brightness at a station, such as 3 MH, is proportional to the candlepower when other conditions, such as viewing angle and pavement surface reflection, are constant.

Hence, inclined plane candlepower curves are independently useful. The brightness produced at a series of stations along a specific pavement surface will increase or decrease in proportion to an increase or decrease in the candlepower incident thereto. This assumes constant angles of driver-observer viewing. The effectiveness of different candlepower distribution in such inclined planes may, if desired, be compared directly, without the necessity of the customary intermediate brightness computations.

REPRESENTATIVE ROADWAY LAYOUT FOR VISIBILITY

The representative roadway and lighting layout and conditions for calculation of relative visibility is shown in Figure 14. The pavement brightness is a major factor. Hence, the pavement brightness stations are considered basic reference points. For example, the visibility at stations at 3. 5 MH longitudinal distance in front of luminaire No. 3 is correlated with the obstacle brightness at 4. 5 MH; this contrast produces visibility which is reduced by the D. V. B. percent reductions in visibility 7 MH ahead of the pavement brightness station or at 10. 5 MH front of luminaire No. 3 (2. 5 MH in front of luminaire No. 1.)

For the representative lighting layout 120-ft (4 MH) staggered longitudinal spacing and 60-ft (2MH) transverse distance between luminaires has been adopted. The method for calculating seeing factors is adaptable to other spacings in multiples of the 0. 5 MH (or 15 ft) actual distance between pavement brightness stations.

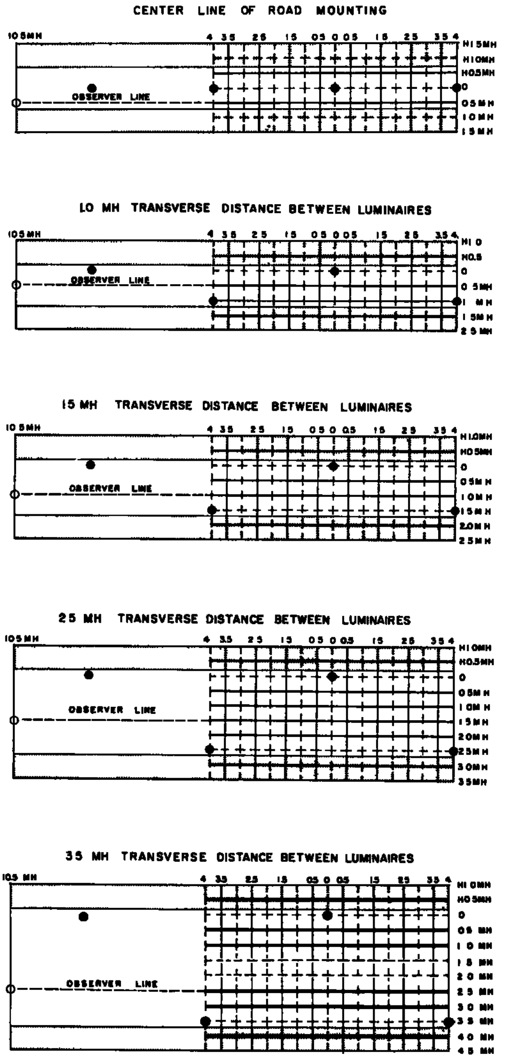


Figure 15. Representative layouts of roadway lines, and driver-observer eye position lines, which will be used in rating factors in seeing with roadway lighting.

The two longitudinal roadway lines, 0.5 MH and 1.5 MH, are assumed to be representative of the traffic-used pavement areas of the typical roadway.

The road brightness stations designated "X" might be typical of those used for field measurement of pavement brightness. However, the pavement and obstacle brightness data have been calculated at longitudinal intervals of 0.5 MH up to distances of 10.5 MH from each luminaire and then combined for the system. At distance of 7 MH (about 210 ft) the driver viewing angle with respect to the pavement surface is about 1.2 degrees. The brightness at this pavement station is contrasted with the brightness of the vertical mid-portion of a 1-ft target or obstacle at a viewing distance of 6 MH. This relative comparison of 6-MH vs 7-MH longitudinal obstacle-pavement brightness is also useful in field testing.

The pavement and obstacle brightness at each of the longitudinal roadway stations shown in Figure 14 is a transverse average of the combined brightness at the respective station distances along the two longitudinal roadway lines, 0.5 MH and 1.5 MH.

The brightness results from incident candlepower from luminaires along both sides of the roadway. The candlepower from each luminaire is derived from inclined plane candlepower distribution curves. Only two such candlepower curves are required for the pavement brightness along the two roadway lines 1.5 MH and 0.5 MH.

AUTOMOTIVE DATA HELP

The 4.3-ft eye-level height is based on 51.7-in. average driver eye height in 25 makes and models of American cars, as of June 1955, according to information supplied by T. J. Carmichael, Engineering Staff, General Motors Corporation Technical Center, Detroit, Michigan.

As indicated in the illustrations, the data are based on top-of-auto-windshield cutoff of the brightness from luminaires at distances closer than 3.3 MH. This is approximately the distance at which the vertical angle of 76 degrees intercepts the driver's eye-level line, as indicated by data available on 1955 cars. This reduces the average luminaire brightness (discomfort) and disability veiling brightness in the driver's eyes even though it is also partly responsible for the peak fluctuations.

The luminaire light distribution used is hypothetical. Except for an increase of each candlepower value by 2.5, this over-all light distribution is similar to that shown in the isocandle diagram (Fig. 15) as given in the Appendix, "American Standard Practice for Street and Highway Lighting 1953."

For information with regard to roadway lines, distance in relation to MH (mounting height) and the 4 MH (120-ft) staggered spacing refer to "American Standard Practice for Street and Highway Lighting" approved February 27, 1953, A.S.A.

SEEING RATINGS FOR TYPICAL ROADWAY LIGHTING LAYOUTS

The I. E. S. Sub-Committee on Roadway Lighting is currently using this method of calculating and rating the seeing factor effectiveness of typical major classifications of roadway lighting and layout, as shown in Figure 15. These ratings may then be compared with average and minimum horizontal footcandles currently prescribed by the "American Standard Practice for Street and Highway Lighting."

Street and Highway Lighting. The user may then compare the seeing factor ratings derived for these examples with his own roadway layouts. Estimates of seeing factor performance may thus be obtained by interpolative judgment with maximum simplicity.

Such simplifications will be welcomed by everyone, including those who may now find it difficult to interpolate between (a) the footcandle levels now prescribed by "American Standard Practice" and (b) the seeing effectiveness desired from a roadway lighting system.

One of the general objectives of the I. E. S. Sub-Committee is to provide a basis for the evaluation of roadway lighting in accordance with the driver's desire and experience. This Sub-Committee now comprises: P. B. Clark, Line Material Co.; W. H. Dorman, Corning Glass Inc.; W. H. Edman, Holophane Co.; M. E. Keck, Westinghouse Electric Co.; H. E. Wall, City of Detroit, P. L. C.; F. D. Wyatt, Consulting Engineer; J. Young, New England Power Service; and Charles Rex, Chairman, General Electric Company.

Ex-officio members include G. K. Glass, Detroit Edison Co.; D. W. Rowten, Westinghouse Electric Co.; and T. J. Seburn, Yale Bureau Highway Traffic.

FIELD MEASUREMENT OF SEEING FACTORS

At Detroit and other locations field measurements are being made of seeing factor ratings under typical roadway lighting installations.

At the University of California Institute of Traffic and Transportation, Prof. D. M. Finch has a new visibility meter under development which may have some advantages over the Low-Range Luckiesh-Moss Meter. He is also investigating three-dimensional targets and other techniques in the measurement of seeing factors. This work has been sponsored by the Illuminating Engineering Research Institute.

Dr. Sylvester K. Guth, Director of Vision Research for the Nela Park Lamp Department, has suggested and is developing a promising and practical device for field measurement of comfort thresholds under roadway lighting. This he calls a "comfort meter box." It is of constant area, with variable brightness, and may be mounted in front of a driver-observer for a calibrated brightness comparison with the brightness of luminaires in the field of view. The equivalent brightness of the controlled and calibrated "box" glare source may provide a "figure of merit" for comfort under roadway lighting.

Dr. Glenn A. Fry of Ohio State University is developing a meter which will integrate and record the total disability brightness in the normal field of view. It is hoped that this device, mounted on an automobile, may provide a quick recording of the disability veiling brightness along representative driver paths under roadway lighting.

SUMMARY

Action for "open after dark" operation of the nation's motor vehicle transportation system must be accelerated. Really significant progress involves acknowledgment of the economic and social benefits to be gained. Progress also depends upon realization of personal accountability to protect and enhance the over-all welfare of the people.

Night usefulness and value of streets and highways depends upon lighting. Although some critical and heavily-traveled sections of roadway have been lighted, more will be properly lighted, the extent depending upon the concentrated attention devoted to night traffic operations. The extra effort is small compared with the importance of the objectives and benefits to be gained.

This paper presents the work of only a small group of engineers and technicians in an area in which the active interest of many is essential. Moreover, it is an effort to interest and implement night traffic progress, both now and in the immediate future.

Observations, appraisals, estimates, and evaluations of the traffic and seeing effectiveness of roadway lighting may not require number ratings any more than that which is obvious. However, as an additional future aid "figures of merit" will be provided.

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