REPORT OF COMMITTEE ON HIGHWAY TRAFFIC

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REPORT ON VEHICLE AND HIGHWAY MECHANICS AS RELATED TO TRAFFIC

HEADLIGHTING[1]

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SYNOPSIS

Report of an extensive series of tests of motor vehicle headlighting including, visibility distances on straight roads, visibility distances in general both with and without opposing cars, spread needed for headlight beams and glare and intensity of illumination needed to enable the driver to see the road shoulder A striking conclusion from the tests of beam spread is that the great emphasis upon sharp cut-off and exact aiming in vogue a few years ago had no rational basis in headlight performance A most important element in avoiding danger in meeting other cars was found to be adequate light on the roadside since sight to the rear of the opposing car is almost negligible Conclusions defining headlighting conditions conducive to best results and suggestions for future study are presented

A rather extended research project was undertaken at the Bureau of Standards in 1927-1928 at the request of the National Automobile Chamber of Commerce and supported largely by funds appropriated by that organization

Part of the results are not in print This section of the committee report covers a summary of the results of the entire investigation including the material not previously published

Tests were of four kinds, which will be explained here only very briefly, although the actual time involves two years of observations running into many thousands of separate determinations

VISIBILITY DISTANCES ON STRAIGHT ROADS

(Straight, smooth, level concrete road)

The object was to determine the actual distance at which typical objects could be seen on a straight level concrete road with headlight

[1] Publication approved by the Director of the Bureau of Standards of the U S Department of Commerce

beams of varying vertical and horizontal spread, vertical tilt and bulb candlepower, all without opposing lights The equipment used for this purpose is illustrated in Figures 1 and 2 Figure 1 shows the test car on which were mounted four separate lamps capable of adjustment in all the respects noted Figure 2 illustrates two of the test objects employed The beam patterns employed were all symmetrical in horizontal distribution Several thousands of observations were made under the widest practicable range of conditions and the following conclusions were reached

1 The distance at which objects can be seen is a maximum when the maximum intensity is aimed horizontally, it drops off sharply when the beam is depressed below this position and somewhat less sharply when the beam is elevated

2 The visibility distance decreases with increased spread of the beam either vertical or horizontal if the bulb candlepower remains constant because the light intensity on the object decreases

3 The visibility distance decreases with decreased intensity whether this is due to greater spread of beam, lower bulb candlepower or poorer reflection, by an amount which is roughly proportional to the cube root of the intensity of light falling on the object

Thus if an object could be seen at a distance of 400 feet with a given beam intensity, a distance of 500 feet could be secured only by using double the candlepower in the bulbs or by reducing the beam 50 per cent in area

(NOTE Some unpublished results obtained elsewhere show even less change in visibility distance for a given change in candlepower)

4 The visibility of different objects varies with size and more particularly with color and character of surface In general for the same lighting conditions a white object was visible for twice the distance of the same object colored black This difference is less than would be expected and is probably due partly to the existing background conditions which obtained in these tests (More accurate figures for these effects have since been obtained by other observers but these results do not affect the general conclusions)

5 Visibility distance does not depend to any significant extent on the speed at which the object is approached

6 A comparison between results obtained with and without moonlight show no significant differences in visibility distance under these two conditions

It should be kept in mind that the foregoing conclusions apply directly only to the limited condition of a straight smooth, level concrete road Some of them are greatly modified when applied to results obtained under a variety of road conditions as explained below

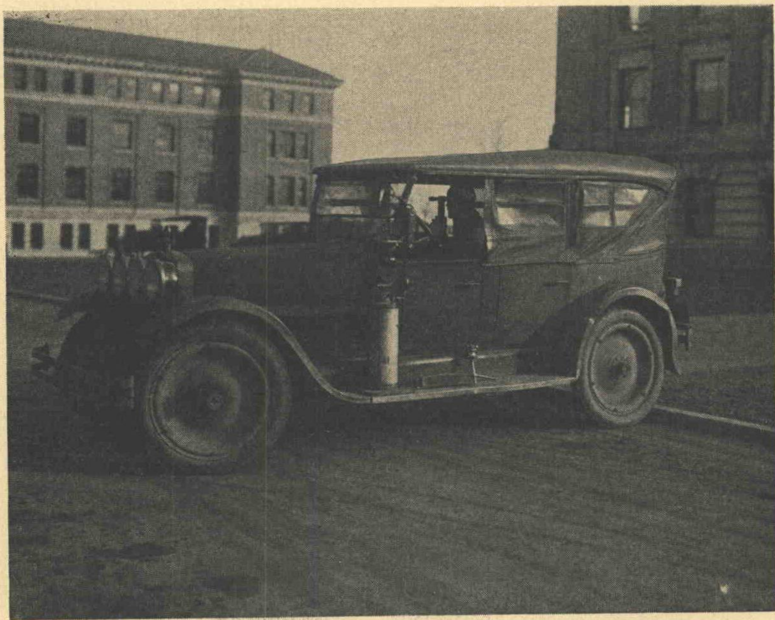

Figure 1

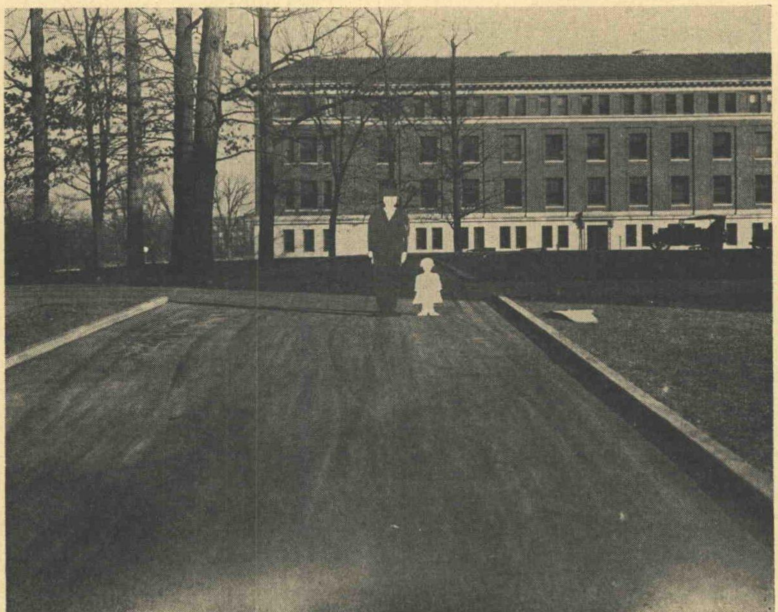

Figure 2

VISIBILITY DISTANCE IN GENERAL

(Average Hard Surfaced Road Conditions)

For the purpose of extending the observations to cover average road conditions both with and without opposing lights a special equipment was devised and used each night for several months to collect the great mass of statistical data on which the following conclusions are based

The equipment consisted of two cars A and B Car A was fitted with the special adjustable head lamp equipment used in the previous tests Car B was fitted with an exactly similar equipment mounted facing the rear and furnished with a black curtain which could be lowered over the head lamps to render them invisible when so required. See Figure 3 This car also carried a special test object so mounted on a right hand door that it could be swung out into view as shown in Figure 4 when observations were to be made. Car B also carried certain signal lamps and markers to assist in observation Car A carried a stadiometer by means of which visibility distances could be measured quickly at all times In this entire series of tests the head lamps on the two cars were always adjusted to the same vertical and horizontal beam spread and to the same tilt as referred to the axis of the car

The test procedure with these cars was to drive car B with its rear headlamps to some chosen location in the road, draw to the left and stop with all lights out (except a safety red light on the front) and the test target swung out so as to be near the center of the highway

Car A then with its driver and observer approached with head lamp on and adjusted for some one of the many conditions to be tried, until the test object just became clearly distinguishable Then at a signal a small target lamp was switched on at Car B and a stadiometer reading taken Next the rear headlamps were uncovered and turned on at Car B and Car A approached farther until the test object again became distinguishable in the glare of the opposing lights The distance was again measured, recorded and Car B proceeded to a new location Throughout a large part of the program measurements were also made at this point of the illumination actually falling in the eyes of the approaching driver This was done with a portable photometer mounted in the windshield of Car A Observations had to be made on unfrequented roads or late at night because of interference with other traffic and of other traffic with the observations

The results of the very long series of observations made with this equipment include the widest practicable range of road conditions, and a wide range of weather conditions all of which are given something like their proper weight They represent therefore a fair approach to the average conditions met with on the road, except that there was only one opposing car and that was stationary, not in motion

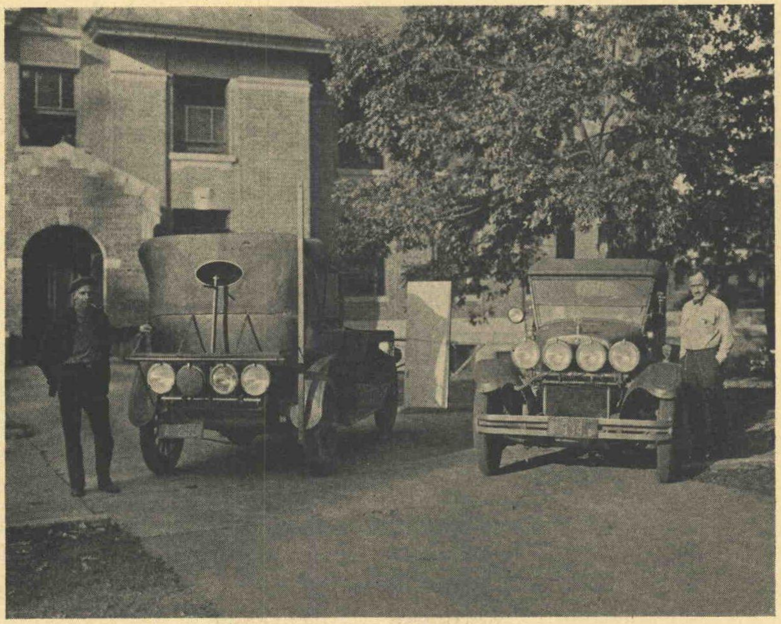

Figure 3

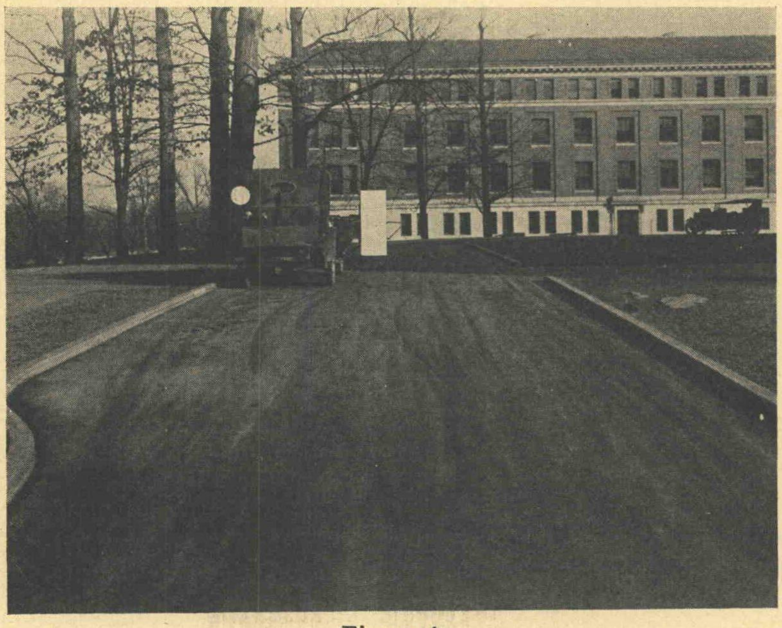

Figure 4

The conclusions may be stated briefly as follows·

1 Horizontal spread of the beam, using the same bulb candlepower has a small effect on average visibility distance, not over 20 per cent for spreads ranging from 8° to 40°, probably due to change in beam intensity with spread

2 Brightness of beam has much less effect on average visibility distance for all sorts of road conditions than for straight roads For an average visibility distance of 300 feet it would require more than a fivefold increase in the bulb candlepower to increase the distance to 400 feet Thus if 300 feet corresponds to 21 candlepower bulbs, it would require more than 100 candlepower to give an average visibility distance of 400 feet

3 The average visibility distance under all conditions of road and horizontal beam width is a distinct maximum when the maximum intensity of the beam is aimed horizontally, it drops to 50 per cent for a 4 degree depression and to 70 per cent for a 4 degree elevation This decrease in visibility distance is less for beams having greater vertical spread

WITH OPPOSING LIGHTS PRESENT

Results with opposing lights, as is to be expected, differ radically from those without such disturbing factors

The results obtained indicate the following conclusions·

1 Increase in spread of the beam from 8 degrees to 40 degrees reduces the visibility distance on straight-aways and curves to the right from 15 per cent to 20 per cent For curves to the left the effect is negligible

2 Vertical tilt of the lamps, quite contrary to the usual opinion, has no significant effect on the visibility distance of objects on the highway, a short distance beyond opposing lights The apparent discrepancy between these measurements, which are not open to question, and the general opinion which doubtless is based on experience that seeing is better with lamp beams depressed, may be found in the assumption that in passing other vehicles it is visibility of the road shoulder to the right and not of possible obstructions in the traffic lane with which the driver is most concerned Road shoulder visibility is improved by lowering the beam In this respect the driver benefits more by the depression of his own lamps than of the opposing lamps

3 The distance at which objects in the right of way just in rear of approaching headlights can be distinguished is surprisingly contant for all conditions encountered This distance seldom exceeded 120 feet and seldom was less than 80 feet The average of all ob-

servations was about 100 feet It should be noted, however, that all observations were made with similar headlamps similarly aimed and adjusted on both vehicles.

4. Within the limits just stated the visibility increases somewhat with decreased amount of light striking the driver's eyes, as measured by the portable photometer. When it is remembered that the eyes of the driver are at a level not much removed from that of the test object which was designed to represent another vehicle or person on the highway, it is evident that elevating or depressing both sets of beams had the effect mainly of changing the general light level, which it is known does not greatly affect visibility

5 The characteristic differences between the results on curves to the right and curves to the left show up in the observations with opposing lights, but as noted above all observations lie within the narrow range of from 80 to 120 feet visibility distance

SPREAD DEMAND FOR HEADLIGHT BEAMS

Since the light intensity and therefore the visibility distance as shown above are affected by the horizontal and vertical spread of the headlight beam for a given bulb candlepower, it is important to know

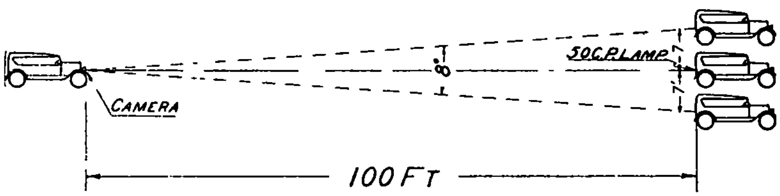

Figure 5 Diagram Illustrating Method of Obtaining Vertical Displacement in the Spread Demand Curves

what should be the minimum vertical and horizontal spread of a satisfactory headlamp beam To secure data on the subject the two cars, A and B, were used as follows · A was fitted with an ordinary camera mounted rigidly on the headlamp mounting with a shutter which could be operated from the driver's seat Car B was fitted with a single low power lamp bulb mounted on the rear near the center of the body Thus when Car B was driven ahead of Car A at any selected distance, with the camera shutter open, a fine line was traced on the photographic plate, giving the angular relationship of Car B to the aim of Car A which was following it. If the road turned to the right the trace travelled to the right and vice versa; likewise for hills and valleys Moreover, spring action or road irregularities on Car A were recorded due to the consequent changes in the axial direction as illustrated in Figure 5

By this means records were obtained showing the various angular positions which would have been required to keep a narrow spotlight beam constantly on the center of the car ahead It is clear that the vertical and horizontal angular spreads then obtained represent directly the angles which must be covered by a headlight beam in order to illuminate directly the vehicle ahead continuously on the particular stretch of road on which these photographs were taken

A large number of such plates were made with the two cars held at distances apart of 100, 200, 300 and 400 feet respectively, at speeds varying from 20 to 40 miles per hour and on a wide variety of roads For each of the four distances a plot was made giving the vertical and horizontal scale of each print in angular degrees, with a figure of the distant vehicle also in its correct angular dimensions Three of these plates are shown in Figures 6, 7, and 8 The last is from an exceptionally smooth flat road

A study of these figures shows that a vertical spread of at least six degrees and a horizontal spread of at least 30 degrees is necessary in order for the headlight beam to fall on any part of a car 200 feet ahead for 90 per cent of the time

The most striking conclusion from these results, however, is that the very sharp cut off at the top of the beam and the accompanying emphasis on exact aiming which were in vogue a few years ago had no rational basis in headlight performance Even on the smoothest level road the beam is continuously sweeping through an arc of three or four degrees which at 200 feet distance includes nearly twice the vertical height of the car Obviously, a sharp cut off of the beam cannot be confined to the space of some four feet between the level of the road and the eyes of the driver, at distances of 200 feet or more This factor assumes greater importance when one considers that visibility distance is proportional to the size of the object, and that the size of that portion of such objects as persons, animals, or horse drawn vehicles, which is visible within a foot or two of the road surface is very small indeed

The results of this series of test were published in the Transactions of Illuminating Engineering Society, January 1929, Vol 24, No 1, p 15, in a paper entitled "Automotive Headlight Requirements from the Drivers Point of View" This paper also included an analysis of the horizontal beam spread necessary for visibility of the road on curves, etc, as related to car speed, showing that for high speeds a spread of 20 to 25 degrees will cover all the field of view which is unobstructed by curves, etc, while at the low speeds necessary on very sharp turns a beam spread of 100 degrees may be needed

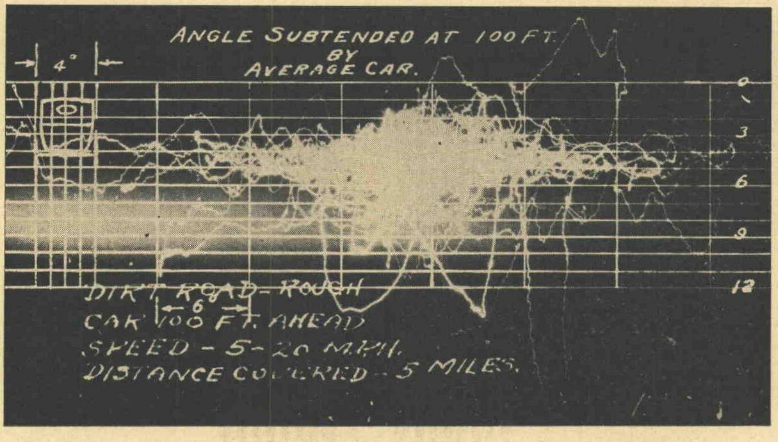

Figure 6

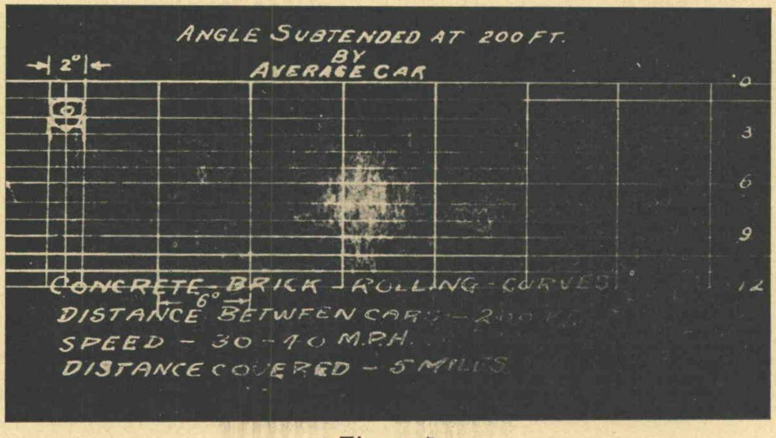

Figure 7

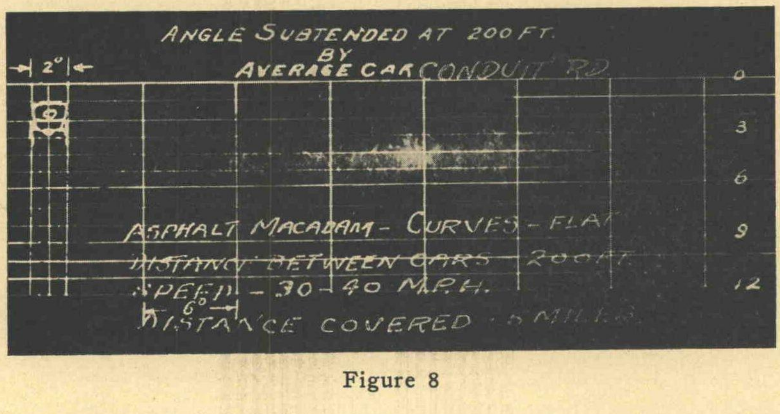

Figure 8

GLARE

A special series of experiments was performed in order to obtain a relation between intensity of illumination in the driver's eyes and that necessary to be thrown on the road shoulder, in order that it might be seen

Two cars were placed on a concrete roadway a fixed distance apart, as shown in Figure 9, the cars remaining stationary The dirt shoulder was flush with the roadway at a fixed point A fixed intensity of illumination was focused directly into the observer's eyes If the intensity of illumination on the road shoulder was not sufficient so that the road shoulder was clearly visible at the instant the light came into the observer's eyes, it was increased until the shoulder became visible The light coming into the eyes was then turned off, the spot on the road remaining, and the process repeated after an interval of 15 to 20 seconds When the series had been completed, the intensity of il-

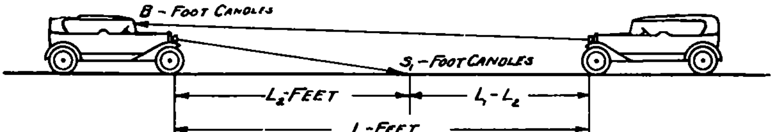

Figure 9 Schematic Diagram of Set-Up Used for Determining Minimum Illumination Necessary on Road Shoulder

lumination from the observer's car incident on the road shoulder was measured

In order to obtain check results several repeat tests were made of each set of observations

Similar observations were made, increasing the distance from the observer, of the spot of road shoulder illuminated, by five foot intervals, up to the total distance between cars, which remained fixed throughout Also, exactly similar series of tests were made, each series with an increased intensity of illumination in the driver's eyes

One observer made all the observations

Data from other sources indicate that the intensity of illumination on the road shoulder for a given intensity in the driver's eyes varies widely, although the probable distribution may be calculated from these data

The conclusions based on these experiments show·

(1) For distances within 25 feet of the driver there must be 1 25 times as great an intensity of illumination in foot candles falling on the road shoulder as that falling in his eyes, in order that he may see the road shoulder immediately after the light comes into his eyes, for

distances up to 45 feet, this ratio is about five; and for greater distances this ratio increases enormously

(2) If, instead of requiring that the driver see the road shoulder immediately after the light comes into his eyes, a time lag is allowed, a less intensity of illumination falling on the road shoulder is required and the greater this time lag, within limits, the less the road shoulder intensity will have to be The effect of this time lag will be greatly different for different persons, as well as greatly different for the same person from one thing to another

(3) If the intensity of illumination at the driver's eyes be increased beyond a given amount, a point is reached where no amount of increase in road shoulder illumination will suffice to give instantaneous visibility thereof. For the observer conducting the tests, and for the condition of his eyes at that time, this limit was somewhat above four foot candles, and all the tests conducted were well below this intensity

The brightest headlamps one is likely to meet on the road could not, in all probability, reach this limit at distances greater than 100 feet between cars For this or shorter distances there is small chance of meeting the full intensity of approaching lights

GENERAL CONCLUSIONS

The more significant general conclusions are as follows:

1. For the best conditions of visibility for open road driving at good speeds in absence of opposing lights, headlamps should be aimed with the maximum intensity horizontal and should have vertical and horizontal spreads of about 6 degrees and 25 degrees respectively

2. For meeting other vehicles and for slow speeds on rough or very crooked roads there should be increased foreground illumination within the first 100 feet and a much greater horizontal beam spread up to about 100 degrees is desirable to give good road side illumination and lighting around curves In these cases the top of the beam should be depressed below the horizontal

3. There is no practicable sort of symmetrical distribution which will make it possible for both approaching drivers to distinguish objects to the rear of the approaching lights for distances much in excess of 100 feet This emphasizes the fact that in meeting other cars the driver depends for assurance of a clear road on the fact that the opposing car has within the past few seconds lighted the road which he is about to pass over. Passing a car at rest involves very much greater danger than passing one in motion

4. The most important element in avoiding danger in meeting other cars is adequate light on the roadside. Sight to the rear of the opposing car being almost negligible, curb illumination must suffice

and therefore must be sufficient for safe visibility when facing the unavoidable glare

5 By far the most serious problem involved in safe headlighting is the great disparity in brightness between different lamps Beam intensities vary more than 10 to 1 even in fairly normal equipment. While this difference accounts for less than a 2 to 1 difference in visibility distance without opposing lights, it results in almost complete lack of visibility for the driver of the dim light when meeting the bright lights, no matter what sort of measures are taken to reduce glare Nine-tenths of the glare problem probably would be solved if the brightness of lights could be kept within a factor of 2 or 3 to 1

FUTURE PROBLEMS

So far as headlighting is concerned, it is important to unify the results which have been obtained and if found correct to apply them to revision of head lamp equipment and to legislation to permit equipment better adapted to safe seeing A rigid requirement as to both a maximum and a minimum permissible beam intensity if practicable would be a long step toward improved conditions Such a minimum however would need to apply not only to new lamps but to all those in use on the road

What appears to be one of the most immediate practical problems, however is a study of the effect of various types of artificial highway lighting on safe visibility There almost certainly are conditions under which some types of fixed highway illumination introduce real hazards as compared with headlighting alone even in the present state of inefficiency. For instance, in any field of fixed illumination by scattered units there are necessarily locations where an object will be so illuminated as to offer no contrast to its background, and hence will become practically invisible. These conditions should be studied and their importance determined

The presence of any exposed light has the effect of greatly reducing the visibility of objects which are dimly illuminated by another source such as the head lamps It results therefore that in some cases objects readily visible by headlighting alone become less visible when fixed lighting is applied

DISCUSSION ON HEADLIGHTING

ABSTRACTED

Mr Cromwell Halvorson, *General Electric Company* Some views are presented illustrating factors that enter into the success of any highway lighting system either portable or fixed Attention is particularly called to the effects of different types of street surfaces upon visibility under natural and artificial lighting, and the suggestion is made that these factors should be taken into account in highway design.

Figure 1 shows two types of pavement, asphalt and concrete, comparing the action of daylight upon them. The lower picture contrasts the two pavements as viewed from directly above, the concrete on the left having a reflection factor of around 80 per cent while the asphalt

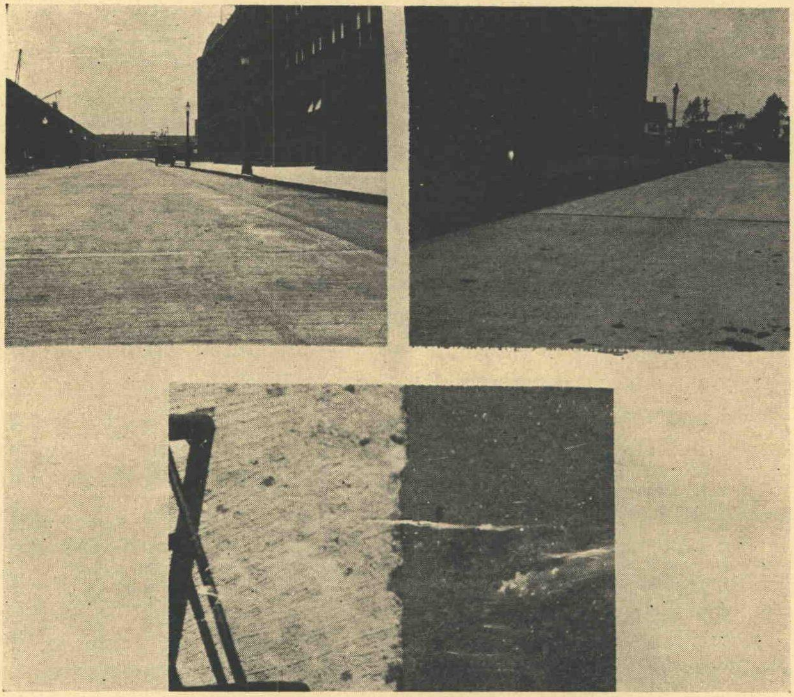

Figure 1. Two Types of Pavement, Asphalt and Concrete. Upper Left Facing Sun; Upper Right Facing Away from Sun. Lower Middle Looking Directly Down on the Two Pavements

on the right reflects approximately four per cent of the light striking it. The upper left view illustrates how the two pavements appear to merge as one when facing the direction from which the light is coming, while the upper right contrasts the pavements as viewed with the light behind the observer. The application of these characteristics on a lighted highway is shown in Figure 2. In addition it will be observed that the traveled lanes marked by oil dripping from automobiles, while reflecting the same amount of light in each case, appear brighter than the concrete on the right, when facing the light and darker on the left when facing away from the light.

The next three views apply directly to Dr. Dickinson's paper on automobile headlights. The first one, Figure 3, was taken with the automobile headlights properly focused in accordance with the specifications of the Illuminating Engineering Society. As shown in the picture, a man in dark clothing facing away from the car a hundred feet ahead of the automobile is barely visible on any dark or wet pavement. Identically the same conditions prevail in Figure 4, except that the use of street lighting forms a perfect silhouette of the man which is easily visible, even though the headlight beam is lowered. This same man in the same position is a little more easily distin-

Figure 2. Highway Lighting Using 2,500 Lumen Lamps. Concrete Highway Separated by Asphalt Showing Effect of Light on Oil Stained Portions of Road.

guished by the headlights when wearing gray clothing, Figure 5, and holding a handkerchief in his hand.

These four views clearly indicate that there is much more to the problem than foot-candle illumination, intensity, direction of beam, etc. While it is probably true, as Dr. Dickinson says, that there are conditions in some present day street lighting under which the illumination of the subject may equal that of the back ground, it would be a rare occurrence to find such exact blending that visibility of the subject would be completely destroyed. Particularly would it be very unusual for a subject to be of such uniform color as to entirely blend into the back ground, as there is usually some little thing which will stand out as much as the handkerchief in Figure 5. In Mr. Halvorson's opinion the danger of a subject blending into the back ground of a lighted street is much oftener enhanced by the blinding effect of on-

Figure 3. Man in Dark Clothing 100 Feet from Camera and Automobile (High Headlights and No Street Lights) Is Barely Visible

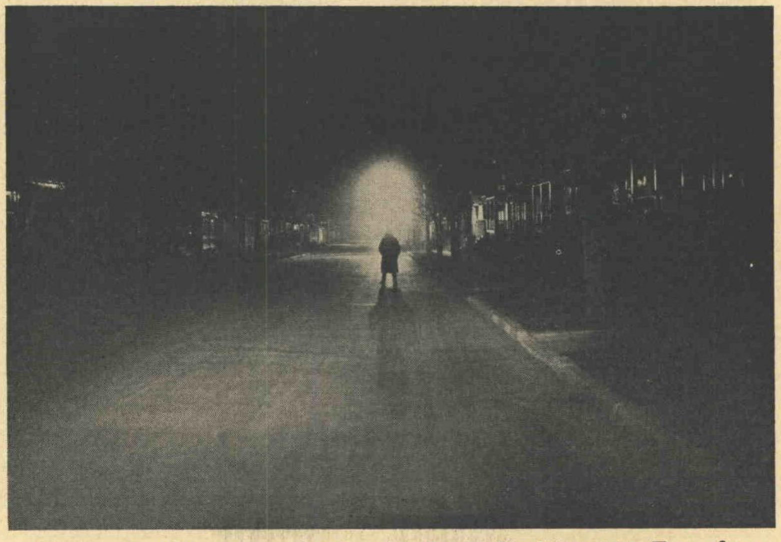

Figure 4. Silhouette of Man in Dark Clothing 100 Feet from Camera and Automobile (Low Headlights) Is Clearly Visible Due to Pavement Brightness from Street Lamps

coming headlights, the glare of which may offset to some extent the value of street lighting and is of questionable aid to a driver as pointed out above. The possibility of such blending would be completely done away with should the street illumination be designed according to the specifications in the Street Lighting Code of the Illuminating Engineering Society, and taking into consideration the question of pavement surfaces on which little work has been done in this connection.

The purpose of this discussion is to enlist the services of the Highway Research Board in the study of street pavements as related to visibility under natural and artificial lighting from fixed sources.

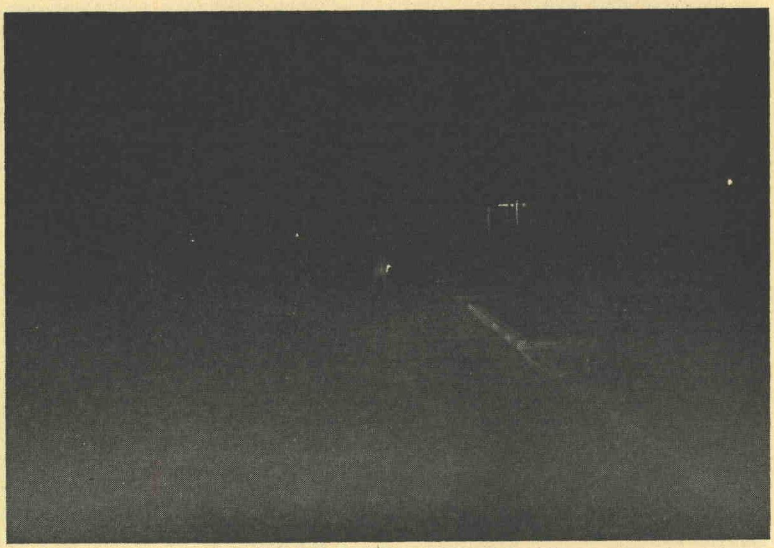

Figure 5. Man in Gray Clothing 100 Feet from Camera and Automobile (High Headlights and No Street Lights) Is Partially Visible

The next few views show different types of pavements in common use and their characteristics when lighted. Generally speaking, all bituminous and asphalt pavements have a reflection factor of less than ten per cent, but some reflect diffusely and some specularly. We have in Figure 6 a bituminous pavement highly polished by the long travel which when lighted reflects specularly as in Figure 7. This is an ideal condition for producing sharp contrasts or what is commonly known as silhouettes. A new bituminous pavement—Figure 8—on the other hand reflects diffusely as in Figure 9, and only areas directly adjacent to the light appear illuminated. A bituminous pavement using small particles—Figure 10—reflects even more diffusely than the above as in Figure 11. On the other hand, a specular reflection—Figure 12—is obtained from mat asphalt and is a great aid to visibility, as it offers

Figure 6. Bituminous Macadam Pavement Highly Polished by Long Travel

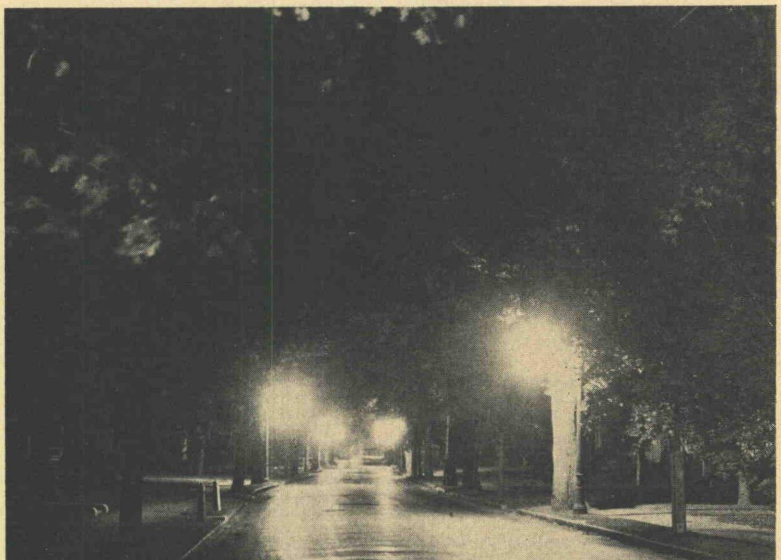

Figure 7. A Light Traffic Thoroughfare with Bituminous Macadam Pavement. 6,000 Lumen Lamps

Figure 8. New Bituminous Macadam Pavement Using Small Particles. Small Disc About the Size of a Quarter

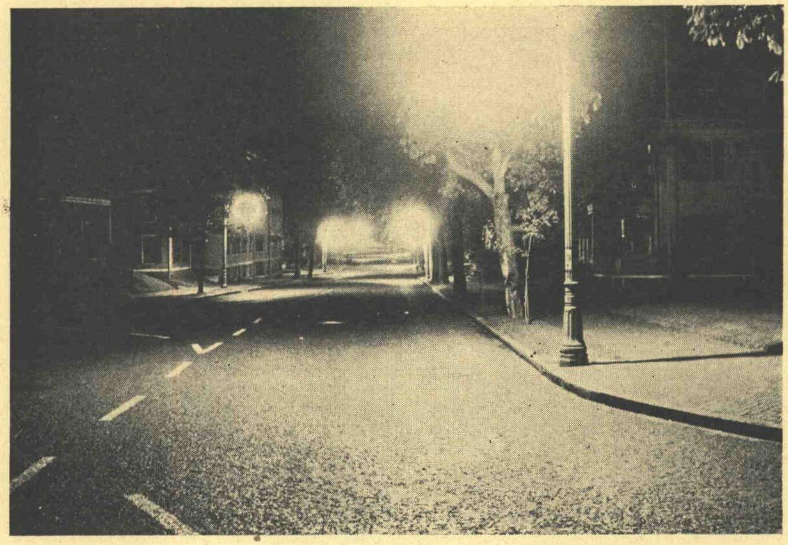

Figure 9. A Light Traffic Thoroughfare. New Bituminous Macadam Pavement Using Small Particles. Detail in Figure No. 8. 6,000 Lumen Lamps

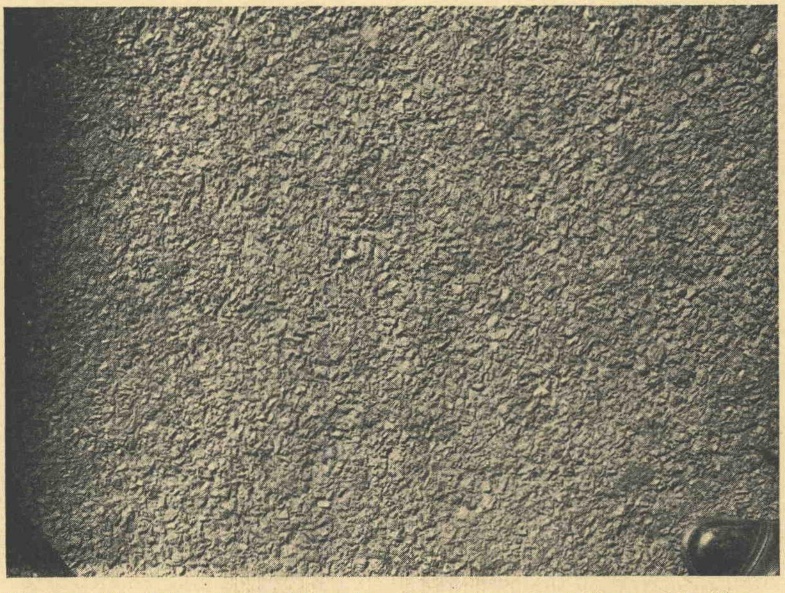

Figure 10. Bituminous Macadam Pavement Patching with Sharp Particles

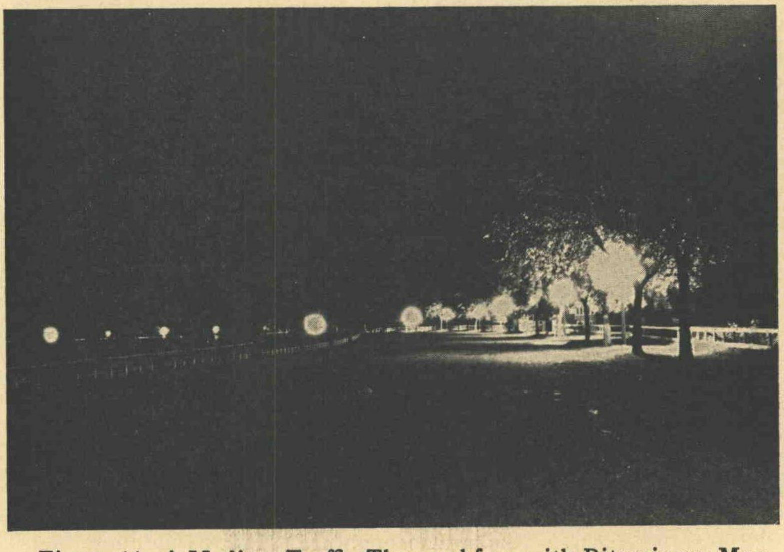

Figure 11. A Medium Traffic Thoroughfare with Bituminous Macadam Pavement Using Small Particles. 10,000 Lumen Lamps. Note Lighted Areas Adjacent to Units

a perfect background for silhouette provided the lights are over the pavement and at the outside of curves.

Bituminous pavement using large rock acts much as other bituminous pavements except that after it has been heavily traveled the rocks begin to work into the binding and the reflection changes from diffuse to specular—Figure 13.

Concrete while it reflects diffusely when dry, reflects a higher percentage of the light which strikes it and so offsets the lack of specular reflection—Figure 14. All pavements assume specular reflection when wet.

Figure 12. A Medium Traffic Thoroughfare with Mat Asphalt Pavement. 10,000 Lumen Lamps. Note the Specular Reflection Is Not Continuous Because Lamps Are on the Inside of the Curve

In closing, the thought is suggested that it seems possible to design road surfaces that will efficiently reflect the light in order to sharpen the contrasts between pavement brightness and objects on the roadway. Furthermore, a pavement might be had of such a design as to reduce the blinding glare of the sun's reflection from the pavement and to increase the efficiency of artificial illumination.

Dr. Dickinson: In his discussion Mr. Halvorson has brought out one point which should be emphasized, viz, that there is much more to the problem of visibility " than foot candle illumination, intensity, direction of beam, etc." The main object in referring to the subject of street and highway lighting was to emphasize the need for more accurate knowledge in this matter. The physiological problem, however, involves some very important factors which cannot be brought out by photographic methods, so much so that photographs are liable to be very misleading.

Figure 13. Highway of Bituminous Macadam Using Large Rock. Note That Specular Reflection Is Beginning to Show as Rock Works Down into the Binder. 4,000 Lumen Lamps, 25 feet Mounting Height, 250 Feet Linear Spacing, Staggered. Units Alternately 8 and 12 Feet from Center Line of the Roadway

Figure 14. Medium Traffic Thoroughfare with Concrete Pavement. 10,000 Lumen Lamps, 20 Feet Mounting Height, 122 Feet Linear Spacing. 11″ Bowl Refractor. Note Well Lighted Appearance of Street, Although No Specular Reflection

Another point which seems to Dr Dickinson to require further careful study is that of objects blending into the back ground It is clear for instance that in any spotty field of illumination there are many positions where this can occur In fact if the object is not large relative to the pattern of illumination the problem becomes very important The relative size of most important objects on the highway is such as to avoid some of the more serious phases of this problem

TRAFFIC CAPACITY

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The investigation of traffic capacity of two-, three- and four-lane highways reported in the Tenth Proceedings of the Highway Research Board was continued during 1931, fifty-six additional stations being occupied As a complete report of this work has been published in the May, 1932 issue of *Public Roads,* Volume 13, No 3, only the results

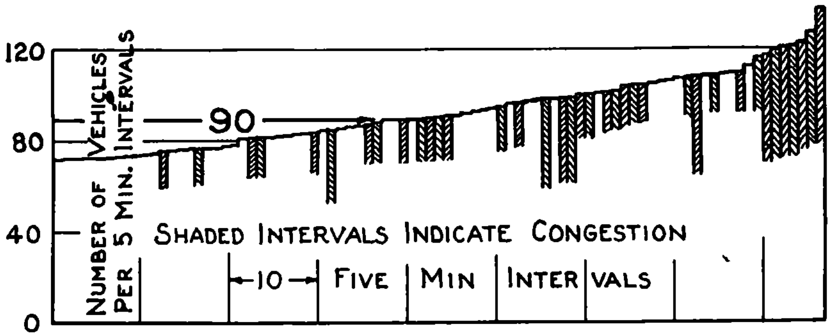

Figure 1 Traffic on a Two-Lane Road with 70 Per Cent of the Traffic in One Direction, Showing That When the Traffic Reached More Than 90 Vehicles Per 5 Minutes, Congestion Became Practically Continuous. The Portion of Each Five-Minute Interval During Which Congestion Prevailed Is Indicated by the Length of the Shaded Area Relative to That of the Whole Interval

additional to those already reported in the Proceedings will be summarized here

In the 1930 observations previously reported no congestion was found on the four-lane roads on which counts were made In 1931 some four lane road congestion was observed The maximum hourly traffic observed on any four-lane road was 3,496 vehicles while the maximum rate per hour for a five minute interval was 3,912, the actual hourly traffic being about 89 per cent of the maximum five minute interval

Figures 1 and 2 illustrate the method used for determining the point of incipient congestion or working capacity under different