FIELD AND LABORATORY EVALUATION OF ROADSIDE SIGN SURFACING MATERIALS

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SYNOPSIS

Physical and optical characteristics of sign materials and design and application of a reflectometer devised by the Kentucky Department of Highways are discussed. Accelerated weathering procedures and specification standards are described.

Field studies paralleling laboratory work and a possible correlation between the two are described. The field work included several thousand individual observations covering 30 different sign-surface types under actual conditions on a night-visibility driving-course. Most of the major types of surfaces available were represented.

In addition to using ordinary sealed-beam headlamps, field observations were made using polarized headlamps and viewers.

Current night-driving habits practiced by the driving public are characterized by a series of assumptions. There is a tendency for drivers to assume their roadway is clear and unobstructed unless forewarned of an approaching hazard, such as a hazard beyond the crest of a vertical curve, a break in the pavement, an intersection, or a congested area. Glaring headlights of approaching vehicles present equally dangerous hazards of a mobile nature. Drivers must rely upon blind faith when passing approaching vehicles: Faith that the vehicle is operating correctly, well over in its proper lane; faith that the roadway does not alter in character or direction immediately beyond the oncoming lights; faith that there is not a pedestrian or stalled car in the roadway immediately behind the glaring lights. Considering the number of people who travel the highways by night, no effort should be spared in providing the best night-driving aides to increase the comfort and safety of the traveling public.

About 1939, the use of minute glass beads for reflectorization of highway signs and markers was introduced. However, the advent of World War II prevented their widespread use until about 1945. During the war several states used all of the material not taken by the armed forces to begin reflectorization of the signs in their highway systems. This conversion was slow and went generally undetected by the public.

Early in 1947, a comprehensive study of the optical and physical properties of reflectorized sign-surfacing materials was instituted by Kentucky. At that time there was no published detailed information available pertaining to these materials, so it was necessary to develop a general knowledge of these materials and their inherent properties.

One of the first forms of reflectorization encountered in this investigation was a type in which the paint-like binder was applied to sign-stock and beads were dusted onto the wet paint-film. This was classified as a Type II surface, Type I being reserved for older, non-reflectorized,

enamel surfaces. Prefabricated sheet materials, extending the classification in order of ascending reflectances, were assigned to Category III. Sub-classifications III-A and III-B were used to further differentiate between materials having a clear-plastic matrix and materials having a pigmented-plastic matrix respectively. These Kentucky Department of Highways classifications are used throughout this paper to facilitate description.

Refractive Index

Ordinary glasses possess refractive indices in the range of 1.52 to 1.65. Special glasses may have indices in the order of 1.90. Optically speaking, the higher the refractive index the shorter is the focal length of a spherical lens. Assuming a refractive index of 2.0, the focal length of a spherical lens is equal to the radius of the sphere. Assuming a refractive index of 1.5, the focal length is 3/2 the radius measured from the center of the sphere. Regardless of the size of the sphere, when $n = 2.0$, the focus is at the axial center of the trailing surface, but when $n = 1.5$, the greater the size of the sphere the farther the focal point is removed from the axial center of the trailing surface. These hypothetical cases are illustrated graphically in Figure 1.

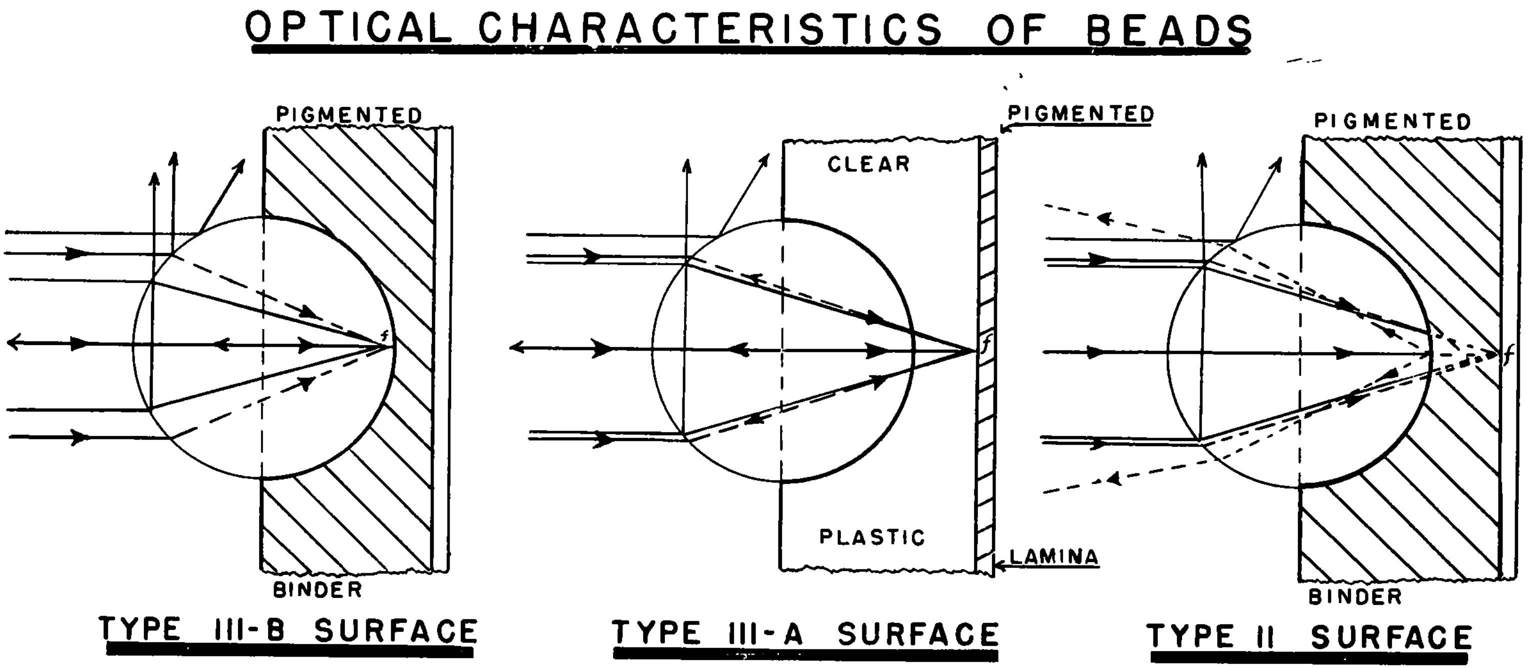
(For the sake of these analogies, the incident light is assumed to be a parallel beam. Actually, light from a headlamp is slightly divergent. Also, the illustration for Type III-A neglects the refractive index of the clear matrix. Where the index of the matrix is approximately equal to that of the bead, the focal length of the system is twice the radius of the bead, measured from the center of the sphere.)

Light entering a Type II surface having a refractive index of 1.5 never reaches a focal point. It illuminates a large area on the reflecting surface which, if considered a battery of point-radiating sources, returns diverging light in the general direction of the original source. When light enters a Type III-A surface, also having a bead index of refraction of 1.5, the light is focused at the reflecting surface by the properly-spaced beads when the illumination is normal to the surface. At other angles the reflecting surface is beyond the focal point and diverging light is reflected. At normal and near normal angles of incidence this surface exhibits high reflectances. For this reason it may be highly efficient under long-viewing conditions where small angles of incidence and divergence are encountered.

The Type III-B surface is shown by the illustration to be an optically-idealized condition favorable to reflex reflection. With a refractive index of 2.0, the focal point is fixed at the axial center of the trailing surface and is otherwise independent of the size of the sphere. Not only does this feature eliminate the necessity for precise spacing of the beads, but it permits the use of graded beads (within limitations). It further permits the use of a more durable binder material. Although pigmented binders are used almost exclusively, it is not inconceivable that a lustrous metal binder may eventually be produced which would furnish additional permanence to a finished sign.

Measurement of Refractive Indices

Glass spheres are ideal specimens for refractive indices measurements by the Becke line method (1). The procedure is simple and may be completed



TYPE III-B SURFACE	TYPE III-A SURFACE	TYPE II SURFACE
Highly refractive, low-silica glass	High-silica, low refractive index glass	High-silica, low refractive index
Refractive index = 2 (approx.)	Refractive index = 1 5 (approx.)	Refractive index = 1.5 (approx)
Critical (grazing) angle = 30° (approx)	Critical (grazing) angle = 42° (approx.).	Critical (grazing) angle = 42°
Effective aperture indicated by 60° chord	Aperture indicated by 84° chord.	Aperture indicated by 84° chord

Figure 1. Optical Characteristics of Beaded Reflecting Surfaces

in 5 or 10 minutes. The determination requires a simple microscope having a small aperture objective and a stage with accommodations for transmitted light. The additional equipment consists of a set of refractive-index immersion liquids, range 1.50 to 2.00, which may be purchased from any of the scientific supply companies; and standard biological glass slides and coverglasses.

A few of the beads are dusted lightly onto the slide and covered with a drop of the trial immersion oil and the coverglass placed over the oil droplet; the beads are then observed with the microscope using transmitted light. The concentric lines move toward the medium having the higher refractive index when the objective is raised. When the indices of the glass and immersion liquid are exactly matched the bead cannot be seen at all. It suffices to define the indices as being between the two closest immersion liquids. Care should be taken to avoid misleading observations on air bubbles that may have been occluded by the immersion liquid.

Durability

The two components of the surface, glass and binder, are considered separately:

1. Glass beads - Glasses are formulated much in the same manner as any other chemical compounds. The usual components are silica, calcium oxide, lead oxide, boron, barium, and potassium oxides. Glasses differ equally as much in optical properties, hardness, chemical stability, and refractive index as they do in chemical composition. Hardness and stability are achieved in low refractive-index glasses by virtue of a high-silica content. The preservation of stability in highly refractive glasses is difficult. As shown in Figure 2 (Series 3) a soft, chemically-unstable bead has shown deterioration under both artificial and natural weathering.

Figure 2 is a group of photomicrographs illustrating the types of materials considered in this study and their appearances after subjection to both artificial and natural weathering. The area shown in each view is roughly one millimeter square. Series 1 horizontally shows specification Type II; at the left, unweathered; in the center, weathered artificially; on the right, weathered by horizontal outdoor roof-exposure. In the same order, Series 2 shows Type III-A material, while Series 3 and Series 4 show Type III-B material, with an unsound bead and with a more stable bead respectively. In each case the artificial weathering was 1000 hours in a carbon-arc weathering chamber, and the natural weathering was 21 months of horizontal roof exposure. Note the similarity in effects of the two types of exposure. The weathered samples are in very similar stages, with the exception that the outdoor samples are darker due to an accumulation of soot and stain from their exposure to the elements, conditions which were not encountered by the samples exposed to accelerated weathering in the laboratory.

Soft, unstable beads may be easily detected by crushing them with a blade or placing a drop of concentrated hydrochloric acid on the surface and observing the results after 5 or 10 minutes under a microscope. A stable glass will remain virtually unaffected while an unstable sample will show etching or complete solution. The acid will have no apparent effect on resinous binders. A Missouri Department of Highways report on traffic paints (2) showed unstable beads to suffer deterioration under simple wetting and drying. Like any other lens, the surface must retain

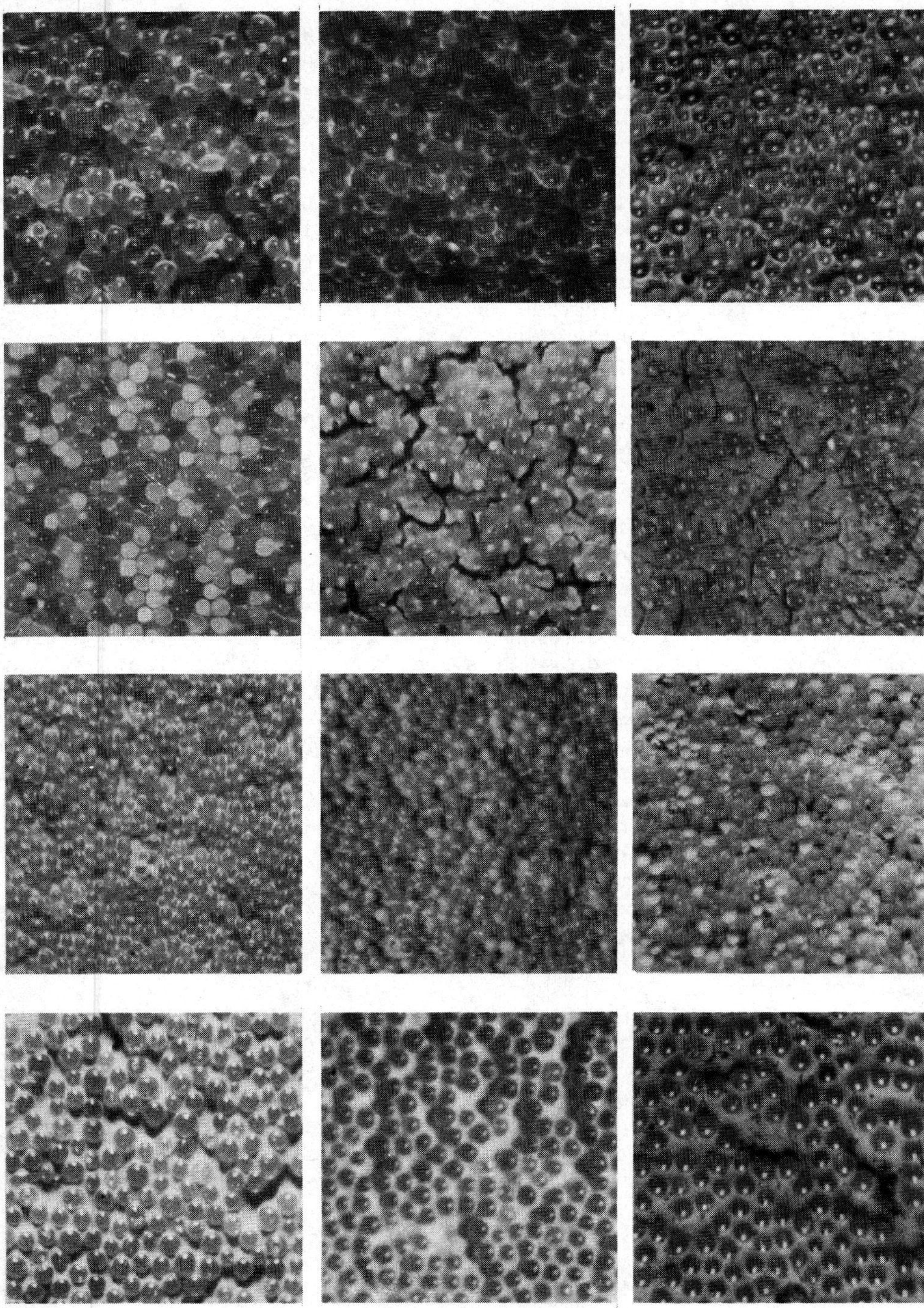


Figure 2. Photomicrographs of Surfacing Materials at a Magnification of Approximately 30 Diameters. The top series, horizontally, is Type II; the second series is Type III-A; the third series is Type III-B with soft beads, and the bottom series is Type III-B with hard beads. Left to right in each series shows unweathered, artificially weathered, and naturally weathered samples.

a high degree of gloss, since otherwise it acts only as a diffuse reflecting surface and is no better than paint.

2. Binder - A pigmented binder is comparable in most respects to a resinous paint. Weathering tests suffice mostly to assure stability of the pigment against bleaching, cracking of the resin, and blistering or peeling due to absorption of moisture. Both Series 1 and Series 4 of Figure 2 have survived severe weathering tests without sustaining any apparent damage. In Series 3 the loss of beads is attributable more to weathering of the glass itself than to the deterioration of the binder material.

In Series 2 of Figure 2, Type III-A, the binder is a clear plastic resin backed up by a pigmented lamina. Here the bead loss is attributable solely to a deterioration of the binder. Failure resulted from shrinkage and drying of the matrix through the loss of plasticiser, and the rate of this loss was probably determined more by heat than other factors of weathering.

Prefabricated materials must be flexible and tough during application to prevent breaking and tearing in handling and subsequent impression over embossed sign stock. Some sheets tend to become brittle after extended storage in a warm, dry atmosphere.

Type III-A and III-B sheets are secured to treated and primed signstock by the manufacturer's adhesives. Adhesives are of two general types: thermo-plastic and solvent-activated. Thus far, the evaluation of adhesives has been considered outside the scope of this research. It will suffice to say that failures or peeling of the surface from the signstock have been rare. If there is any peeling it generally occurs at the prime-metal interface due to corrosion of the metal itself.

Bead Size

Bead sizes may be measured very accurately by drawing a straight pencil line on a section of the surface or sheet and measuring about 100 beads along the line with the aid of a microscope equipped with a micrometer eye-piece (previously calibrated against a stage micrometer). By this method the percentages corresponding to standard sieve sizes can be calculated. Of course, when beads and binder are obtained separately sieve analysis may be obtained directly.

The samples of Type II materials observed thus far have generally had larger beads than the prefabricated sheets. Over 95 percent fell within the range from 0.10-mm. to 0.20-mm. and averaged about 0.15-mm. Type III-A materials are limited to greater uniformity in bead sizes ranging from about 0.10-mm. to 0.15-mm. and averaging about 0.12-mm. Since Type III-B materials are not so restricted with regard to bead sizes, averages for small-bead samples may be in the order of 0.05-mm., while for large-bead samples the average bead size may be as large as 0.15-mm. to 0.20-mm. No significant relation has yet been shown between average bead sizes and reflectances for Type III-B materials.

Reflectance Measurements

In addition to an evaluation on the basis of durability, it was necessary to devise a system for measuring the reflectivity of these materials under angles and conditions actually encountered in service on the road. Preliminary studies of commercially available instruments revealed that

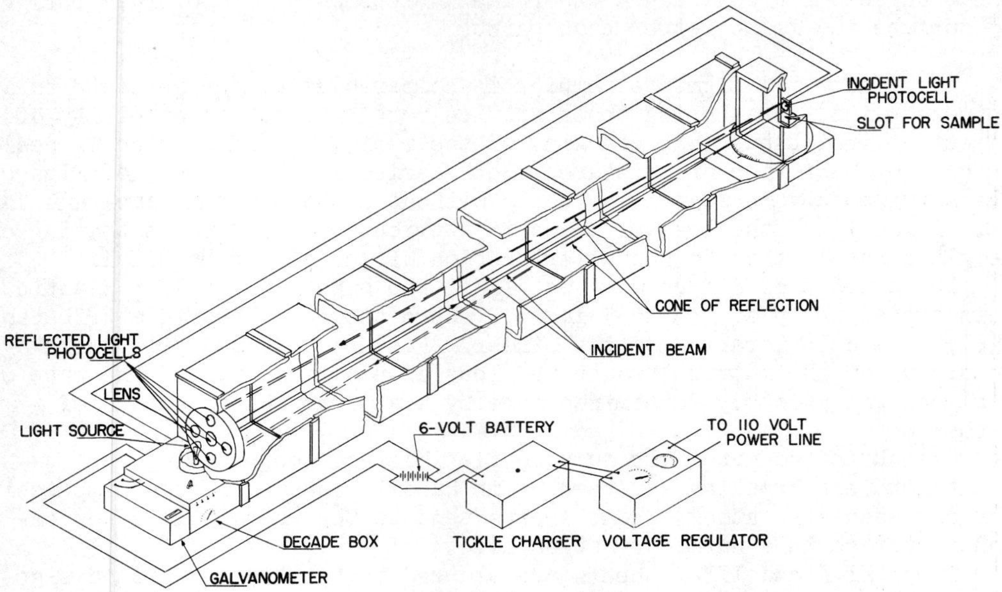


Figure 3. Pictorial and Schematic Diagram of the Reflectometer.

none was directly adaptable to the requirements. Of course, it was apparent that such an instrument would necessarily be of a photoelectric type. With due recognition of the limitations inherent in any photoelectric device, the reflectometer, diagrammed in Figure 3 and shown in Figure 4, was designed and built.

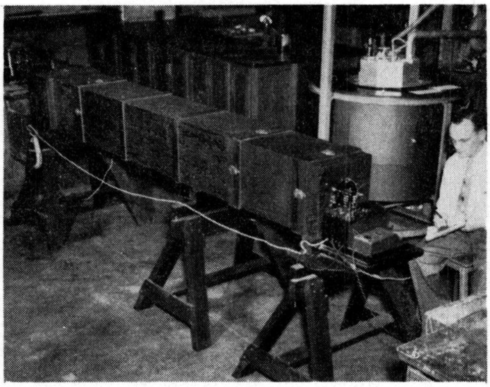


Figure 4. The Reflectometer Assembled for Measurements of Reflectance at 1 Deg. Divergence and 2 Deg. Incidence.

Briefly, this instrument utilizes a parallel beam of light from a standard, 50-candlepower, 6-volt headlamp bulb projected by a lens system onto a 2 in. diameter area of the sample. A photocell is provided at the specimen end of the instrument for measuring the amount of light incident on that area. Four photocells are mounted around the perimeter of the light-projecting lens to measure the intensity of light reflected in a cone representing the cone of vision. This intensity of reflected light, expressed as a percentage of the incident light, is taken as a measure of the reflective efficiency of the specimen. The specimen holder is pivoted and provided with a goniometer scale by which the angles of incidence can be varied from 0 to 30 deg. The angle of divergence of the reflected cone is varied by interchangeable tunnels of length appropriate to provide angles of $\frac{1}{2}$, 1, $2\frac{1}{2}$, and $4\frac{1}{2}$ deg., simulating distances from about 50 to over 400 ft. on the road.

The photocell output is indicated on a suspension galvanometer provided with a decade-box shunt-resistance system for changing the sensitivity

of the galvanometer. The photocells were individually calibrated against a Weston standard foot-candle meter, and the galvanometer was similarly calibrated against a Weston standard micro-ammeter.

These four factors: optics, refractive indices, durability, and reflectance, served as the basic criteria in the establishment of a specification for the materials.

Field Evaluations

In order to determine what laboratory tests meant in terms of field performance, a field-testing project was instituted to determine: (1) the relationship between reflectance and average effective sight distance, (2) the relationship of target size to average effective sight distance, and (3) how reflex-reflector materials perform under polarized headlights with polarizing viewers.

Field Procedures

Considerable thought was given to the choice of a field location for the night-driving course. An access-road to a military installation was chosen because it was reasonably close and of good concrete construction with modern grade and alignment providing good pavement, shoulder, and right-of-way viewing conditions. Since it was not a through highway traffic was extremely light, except when workers were leaving or reporting. Those times were conveniently avoided so far as night observations were concerned. The road was about 2-miles long, and with signs located on both sides of the road its effective length was 4 miles. Two sets of 12 signs were used on the road, one for each direction.

Another convenient feature of this road was the fact that the joint-spacing was 20 feet, which facilitated distance determinations. Because of this feature, it was deemed adequate to mark off the 100-ft. distances in front of each sign and use the joints to determine the intermediate distances. Thus the roadway approaching each sign had large numerals painted on the surface in the middle of the right-hand lane indicating hundreds of feet up to 800. Approximately the same technique as used by Forbes and Holmes in 1938 (2) was used to determine effective sight distances, except that in this case the course was driven at night with the driver acting as the observer and with distances painted on the road surface.

After all of the signs were placed and the distances marked off, liberal numbers of observers were obtained through the cooperation of the College of Engineering of the University of Kentucky. Three or four complete sets of observations were made each night for an average of about three nights a week at random intervals for about a year. This large number of observers was used in order to assure true averages for the group and to prevent unique individual differences from affecting the results. The average age of the observers, however, was about 20 years, so therefore their eyesight may have averaged somewhat better than that of the average driver.

Three identical models of the same make of automobile were used in the field work. One was used with its standard, sealed-beam lights while the other two (shown in Fig. 5) were equipped with polarized lights in the place of the sealed-beam lamps in the regular fender mounts and PAR-46 traffic lamps mounted inboard and connected to serve as the low, or deflected, beam for the car. Each of these two cars was equipped with a

necessarily larger generator and with two polarizing viewing filters, one for each of the front-seat passengers.

Aside from the sign evaluation, it was of interest to see how effectively the Polaroid headlighting system eliminated the mobile glare hazard. Figure 6 is a photograph representative of the condition now universally prevalent in night driving.

Figure 5. Two of the Cars Used in the Field-Testing Program. Both were equipped with polarized headlights, PAR-46 traffic lights, and polarizing viewers.

In contrast, Figure 7 shows a similar encounter in which both cars are using polarized lights and viewers. The result is a great reduction in glare and an increase in viewing distance and eye comfort. These photographs were made on the night-driving course using a properly oriented filter on a view-type camera. Exposures were in the range of 3 minutes at an aperture of f/6.3 with a fast panchromatic film. Because of these long exposures it was necessary to mount the camera on a tripod outside the car away from vibrations due to the idling engine. The sign on the right and the approaching car are 200 ft. from each other while the sign visible in the background is 1000 ft. from the approaching car.

The procedure on the night-driving course was to place two persons in each car, one driving and acting as the observer and the other sitting beside him with a data sheet acting as recorder. The driver proceeded along the course at about 20 miles per hour and identified each sign as soon as he could recognize its design. The recorder then picked up the distance at that point from the pavement markings and entered it on the data sheet. After driving the full course, driver and observer changed places and repeated the procedure. At the conclusion of this second trip around the

Figure 6. Photograph of an Oncoming Vehicle Using Regular, Sealed-Beam Headlights.

Figure 7. Photograph of Vehicular Encounter Using Polarized Headlights and Viewers.

course the lighting conditions were changed and the whole process was started over again.

Each subject drove the course under five lighting conditions by using, in order: (1) Regular sealed-beam headlights, (2) Polarized headlights with no viewing filter, (3) Polarized headlights with the viewing filter, (4) PAR-46 traffic lamps without viewer, and (5) PAR-46 traffic lamps with the polarizing filter.

From this it is easy to see why only four or five observers could be used each night, since each one had to make a total of 124 observations and drive a distance of about 40 miles.

The observers were cautioned to give the signs a fair evaluation and not to guess at their identity or attempt to memorize them. A member of the staff of the research laboratory rode in the back-seat of each car to assure compliance with these regulations and to answer questions of procedure as they occurred to the observers while driving the course.

Figure 8 shows the four targets used in the field work. The first group of signs used were regulation-yellow curve-delineation signs, shown in the upper left, which differed from each other only in the direction in which the arrow pointed. The signs were selected to cover a wide range of reflex-reflective material then available. Data pertaining to this set of signs are of primary importance since this type of sign is in wide service.

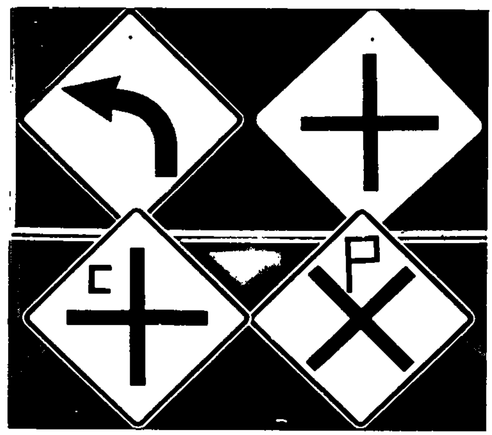


Figure 8. The Four Target Types Used in the Field Evaluations. All are on standard 24-inch by 24-inch metal sign stock.

A second set of signs placed on the course were obtained directly from the manufacturers and represented the range of materials covered in the first group plus some higher reflective types which had just been developed and were still in the experimental stages. These signs were coated by the various manufacturers on regulation steel sign-stock supplied by the Division of Traffic, Kentucky Department of Highways.

The first target used on these surfaces was presumed to be the largest possible message the signs could convey. Each sign had a large plus or X placed across its face (Fig. 8, upper right), and the observers were offered the decision as to the target identity as soon as it could be interpreted. This large target was used in an attempt to determine the maximum distance at which standard-size signs of various reflectances could convey a message.

After a suitable number of observations on the large target, a smaller, 4-in. letter of 3/4-in. masking tape was placed on the same surfacing material (Fig. 8, lower left). The C's and O's were chosen because they have the same general configuration, only the opening in the right side of the C distinguishes between the two, and the size was representative of the smallest practical letter for road signs. Then 8-in. letters of 3/4-in. width, used on the standard 24- by 24-in. stop signs, were chosen as an intermediate size (Fig. 8, lower right). This time the target letters were R's and P's, for the same reasons of similarity in configuration as

explained before.

In each of the latter two cases only one of the letters was put on each sign, and the placement was at random so that the order would be difficult to memorize even subconsciously. As a result of this the decision of the observer rendered a more definite point of recognition than could otherwise have been achieved. In all, over 100 observers were used and over 12,000 observations made.

Correlation of Field and Laboratory Data

Correlation between the field and laboratory data is shown graphically in Figures 9, 10, and 11. Figure 9 shows the results for the standard curve-delineation signs for the three types of lighting with no viewing filter in use. Thus each curve represents a plot of the relationship between average effective sight-distances for one lighting condition and reflectance as measured in the laboratory by methods defined earlier. It is evident that as reflectance is increased up to about 0.20 there is a proportional increase in the effective sight-distance. Above this point, however, increasing the reflectance of the sign surface has little effect on the average effective sight-distance. Visual acuity is considered the limiting factor here, and there is evidently an optimum value of reflectance above which an increase is of no value in extending the distance at which the sign is effective.

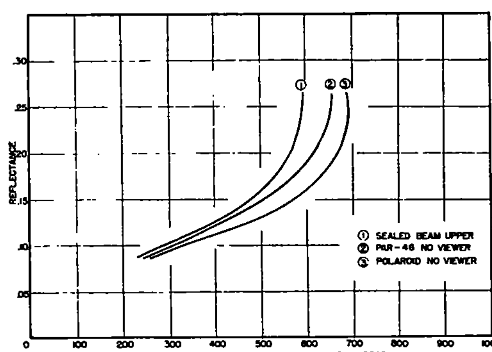


Figure 9. Relationships Between Effective Sight Distances and Reflectances of Signs under Three Different Headlighting Conditions and Without Viewing Filter.

In general, the Type I signs are represented on the curves at reflectances in the range about 0.10. Type II materials range between 0.10 and 0.15, while Type III sheeting accounts for the remainder of the high end of the curve. There is, of course, some overlapping of these ranges and no sharp point of separation can be identified.

Figure 10 shows the same data for the same set of signs except that the polarizing viewing-filter was used with the PAR-46 lamps and polarized lamps. The use of the polarizing viewer with the non-polarized PAR-46 traffic lamps results in their being slightly less effective than the sealed-beam uppers. This is as might be expected since the traffic lamps are designed to replace the sealed-beam lower or deflected beam for city driving and for passing cars not equipped with polarizing viewers as protection from the polarized headlamps.

In Figure 10 the points are shown from which the curves were drawn. This was done because the use of the filter resulted in rather erratic data as compared to the same condition without filter. Note that the points for curve No. 1, which is representative of all the curves for unfiltered viewing conditions, fall into a very smooth curve. However, when the filter is introduced the data are not so well aligned and thus it becomes necessary to average these points with a curve. This irregular performance with the filter may be attributable to differential-absorption effects of the filter toward the signs, which were of various shades of

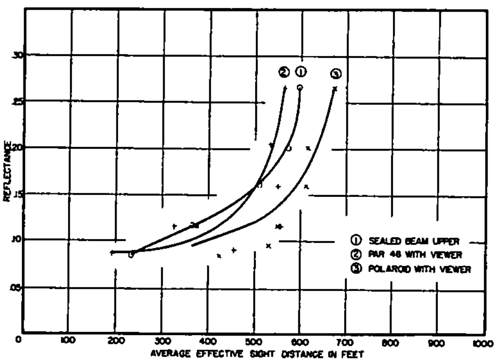


Figure 10. Relationships Between Effective Sight Distances and Reflectances of Signs under Three Different Headlighting Conditions and with Viewing Filter.

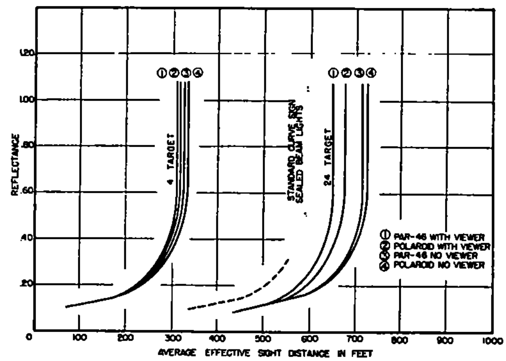


Figure 11. Graph Summarizing the Relationship Between the Laboratory-Measured Reflectances and the Field Data.

yellow.

Figure 11 is a summary of all of the data obtained from the field work. Note here that the range of reflectance has been increased by the addition of some highly-reflective surfacing materials. For this reason the scale is diminished as compared to the previous two figures. The standard curve-delineation sign under sealed-beam lighting is shown on this graph as a dashed and dotted line. The dashed portion of this curve is the same as curve No. 1 in Figures 9 and 10. The dotted portion is an extrapolation of these data into higher reflectance ranges.

A family of curves has been defined by the data for each target size and the five lighting-viewing conditions. The family of curves on the left represents the data obtained with the 4-in. letters, the smallest letters, and the family on the right results from the use of the largest design. The intermediate 8-in. letter is not shown since it fell, as might be expected, between the two extremes.

Note that the separation of the curves within a family increases with an increase in design size. This means that with larger target sizes an increase in the incident light has a larger effect on the sight distance than it does with the smaller targets. These curves again show that above reflectance values of approximately 0.20, the advantageous increase between sight-distance and reflectance is lost. This excludes the factor of prominence, or the capacity of a highly reflective surface to attract attention, even though the message may not be read. Higher reflectances may contribute to the attention factor. But they do not greatly increase the distance at which the message of the sign is effective.

Applications of the Data

So far as the use of the laboratory data and techniques is concerned, specification requirements for three general classes of materials were established in 1948. Aside from minor revisions, the need for which became apparent in the light of experience, this specification has served the Kentucky Department of Highways, Division of Traffic, quite satisfactorily in the purchase of reflectorized sign-surfacing materials since that time.

Results of the field observations at this early date have not been worked into practice so specifically. However, the significance of the results is apparent, and they do provide a basis for estimating the effectiveness of materials in the different specification classes. Conversely the field data offer a straight-forward approach to selecting the range of reflectance appropriate for any set of rural night-driving conditions.

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