Effective Use of Reflectorized Materials on Railroad Boxcars

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● SINCE Koenig (5) it has been recognized in scientific circles that acuity in seeing is a function of the intensity of the stimulus. Luckiesh (8) has identified two primary factors of visibility: (1) luminance or brightness level and (2) brightness-contrast ratio between the object and the background. Hecht (2) has since founded a theory of vision on the differential sensitivity of the receptor elements of the eye, that is, between different rods and different cones.

More recently, Forbes and Holmes (1) have reported that legibility distances of reflectorized highway destination signs decrease when used with a semi-illuminated background. This, of course, would be expected since the brightness-contrast ratio is decreased. Conversely any high-level brightness of the stimulus will increase visibility. It should therefore follow that any object which emphasizes the two factors of seeing enunciated by Luckiesh will be more easily seen at night and will require less impinging light for visibility.

In an earlier study, Lauer and Helwig (6) showed that reflectorizing a stop sign by aluminum or gold paint would materially aid in rendering the sign more-efficient at night. Since that time a great deal of improvement has been made in reflectorized materials and their usage has become very widespread for increasing the effectiveness of signs and markers at night.

The National Safety Council, as early as 1938, recognized the problem of train-car accidents at night. According to figures released at that time, there were 3,089 accidents of motor vehicles at grade crossings in 1938 which resulted in death and injury. Of these, 1,639 occurred in daylight and 1,450 occurred at night. It was estimated that not over a third of all driving in the United States is done at night. Calculated in terms of percent and equating for miles travelled, it is estimated that night accidents constituted 64.3 percent of all such mishaps as against 35.7 percent which occur in daylight, so far as motor-vehicle collisions with trains are concerned. In other words, there is twice as much liklihood of an automobile-train accident occurring at night as in daylight.

From another point of view, the dangers of night driving were even more realistically portrayed. In 1941, Lauer and Silver (7) noted that during daylight only 4 percent of such accidents occurred in which the motor vehicle struck parts of the train behind the locomotive. At night 36 percent of this type of accident happened in such a manner. In 1952 3 percent of cars involved in such accidents struck the train back of the tender in daylight, while 25 percent hit the train at similar points after dark, indicating a short seeing distance. It is thus shown that the danger of an automobile running into the side of a train is eight or nine times greater at night than in daylight. Any defect or condition which shortens the range of accurate vision in low illumination probably increases the liklihood of accidents at night. A correlation of 0.89 between visibility thresholds and legibility thresholds was shown by Stone and Lauer (10).

To indicate the persistence of the problem, in 1952 the National Safety Council reports that 1,348 motor-vehicle drivers were killed in accidents involving collisions with railroad trains. These were about equally divided between urban and rural areas. Sixty-four percent of the accidents involved trains going less than 30 mph. or were standing, and a majority were regular freight, switchyard, and work trains. Forty-eight percent of the fatal accidents reported occurred at night in which drivers ran into the side of the train. In most cases it would be logical to assume that the driver did not see the train in time to prevent the accident. Whatever may be the case, it is obvious that if a driver sees an obstacle in the path of his automobile, in time, he will usually be able to avoid collision.

In addition to deaths there were 3,700 nonfatal injuries of this type, 3,200 of which were in urban areas.

INTRODUCTION

Hoppe (3) made a study designed to obtain certain data relating to a driver's perception of a vehicle being overtaken on the highway at night. Variations in contrast of the lead vehicle were obtained by using panels of different size and reflection characteristics. The following summarization was made from the study: (1) increasing the horizontal visual angle reduced the time for the perception of the direction of relative motion between the vehicles and (2) with a contrast of sufficient magnitude, increasing the horizontal or vertical visual angle reduced the time for perception of the direction of speed differential. Potentially high driving speeds of modern cars greatly emphasize the importance of the time element.

Hoppe and Lauer (4) further established the fact that increased perceptibility would decrease judgment time and errors in the discrimination of relative motion. Anything which gives greater definition of the vehicle ahead increased both speed and accuracy of perception of relative motion, or changing distances, between two vehicles travelling the same direction on the highway.

Experiments were made in the laboratory as well as on the highway using speed differentials up to 10 mph. and the two sets of data showed high agreement. It was therefore concluded that laboratory studies provided a valid approach to the problem. The great economy in time and effort in laboratory tests would not seem to warrant running outside observations. Not only was the expense greater for the latter but there were many hazards involved and it was difficult to control conditions.

Stalder and Lauer (9) studied the effect of pattern distribution on perception of relative motion at low levels of illumination. They found that the pattern distribution of reflectorized material affected the time and difficulty for perception of relative motion. An outline pattern gave better overall results, using a given amount of reflectorized surface, than equal distribution of reflectorized materials spread over the total area in checker-board design.

THE PROBLEM

Three series of experiments were designed to test the efficiency of different types of markings for reflectorizing the side of boxcars. The hypothesis set up for experimental investigation is stated as follows: The addition of limited areas of reflectorized material on the side of boxcars has an effect on the discrimination of lateral motion under conditions of mesopic vision.

A corollary hypothesis may likewise be stated as: The amount and distribution of reflectorized material on the side of boxcars proportionally affects the level of visibility and accuracy of perception of lateral motion.

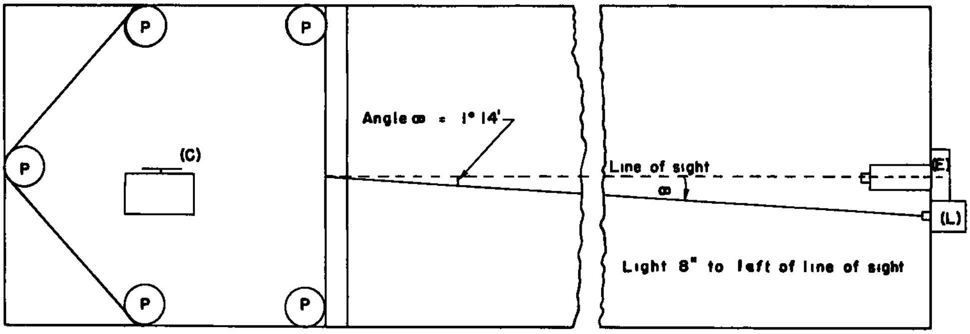
It is hoped that the study may yield data which will provide principles that may aid in providing the most-efficient method of reflectorizing railway boxcars in order to effect the greatest possible protection to the driving public as well as to the railway companies.

The design of the experiment for testing the foregoing hypotheses involved the following assumptions: (1) the data obtained by the experimental conditions used and procedure followed give a valid basis for evaluation; (2) calibrations of lights and lighting of the apparatus and that found under actual conditions of the highway give a fair comparison of light levels needed for threshold measurements; (3) extraneous cues for determining speed and direction of target, e.g., noise, shadows, or reflected light were negligible; (4) rotating the order of presentation of the various stimuli used sufficiently neutralized any systematic errors of practice, fatigue and other possible sources of variance; (5) individual differences of the observers affected all experimental conditions used in a similar way; and (6) all subjects were motivated to give a satisfactory judgment in the experimental situation.

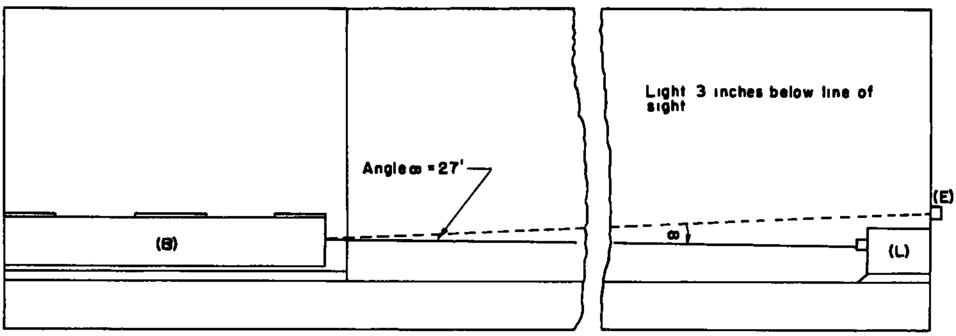
APPARATUS USED

The apparatus used consisted essentially of a dark tunnel approximately 40 feet long and having a carriage (c) mounted at the end opposite the subject. Five flanged pulleys (p) were mounted on the carriage (Figure 1-A) which carry the test belt as it rotates in a vertical position. The belt may be moved in either direction by a reversing switch in order to vary the presentation. Laced to the primary belt is a thin belt on which designs of miniature boxcars are painted. The boxcars (BC) are visible through an aperture (A) mounted on the front of the carriage (C). (See Figure 1-C). The cars (BC) appeared in the opening of the aperture (A) as they move past approximately 29 feet distance from the eye (E) of the observer.

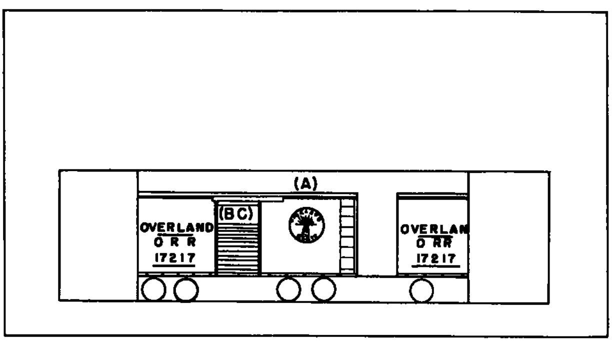
For the first and second series, the luminant (L) was a Ferree-Rand acuity meter used as a projector. An adjustable diaphragm calibrated for the percentage of opening controlled the amount of light as needed. The light source was mounted at the same height and eight inches to the left



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.

of the subject's line of vision, subtending an angle of 1 deg. 14 min. This is shown by Figure 1-A.

For Series 3 a Viewmaster Model S-1 projector was used as the luminant (L) with a Variac control. This light source was mounted 3 inches below the line of vision and the subtended angle was 27 min., as shown in Figure 1-B. Illumination levels were calibrated by a Weston Photronic cell with Viscor filter and a portable Leeds and Northrup d'Arsonval galvanometer. Only visible light is measured by this cell.

DESIGN AND METHOD OF PROCEDURE

Three series of experiments using 30, 30, and 25 subjects, respectively, were run. The first series was considered a pilot study and the data are not presented here.

In Series 2 the following experimental conditions were presented to the 30 subjects for a total of 1,260 observations as follows: (1) no reflectorized material on the side of the boxcars; (2) eleven 3/32-inch-square pieces of reflectorized material spaced an inch apart at the lower edge or sill (S) of the car, the equivalent of about 4-inch squares spaced 4 feet apart; (3) same as Series 2 except that the name of the railroad and the number of the car were in reflectorized paint. In Series 3 the same experimental conditions were presented to each of 25 subjects totaling 1,050 observations using a Viewmaster projector for the light source (L) as shown in the middle sketch, Figure 1-B.

In the second and third series each experimental condition was presented to the subject 14 times and the order systematically rotated in an effort to cancel out such factors as practice and fatigue. Reliability of the observations was 0.97. These are estimates computed from the correlation of the odd and even trials using the conventional formula. All subjects were first given a visual acuity test and only those having 70 percent vision (Clason notation) or above were used in the experiment. This is slightly better than 20/30 Snellen acuity.

TABLE 1

COMPARATIVE LEVELS OF ILLUMINATION ON BOXCARS, SERIES 2

Means and standard deviations for the three experimental conditions

Experimental condition	Units of light - mean*	Ratio of light needed with respect to condition 3 as unity	Standard deviation
Condition No. 1	214.00	31.3	62.42
Condition No. 2	175.40	25.7	51.19
Condition No. 3	6 83	1.0	2.53

*Mean score. Score was total of 14 readings for shutter opening on Ferre-Rand acuity meter.

TABLE 2

EVALUATION OF DIFFERENCES FOUND, SERIES 2

Values of t for the mean amount of light necessary to determine the direction of motion between experimental conditions used

Experimental conditions	Value of t
Condition No. 1 Condition No 2	2.62*
Condition No 1 Condition No. 3	18.19**
Condition No 2 Condition No. 3	18.06**

* Significant at the 5-percent level
** Significant at the 1-percent level.

The absolute units were not comparable with Series 3 since a different system of illumination was employed.

Wide differences are here noted between Condition 3 with each of the other two. Thus the fully reflectorized name on the side of the boxcar was far superior to the small, 4-inch diamonds placed along the sill. It is hypothesized that larger concentrations of reflectorized materials, spaced further apart, would be more effective and further experiments are being designed to test this hypothesis.

Because of the physical limitations of placing the luminant so that the angle of impinging light formed with the line of vision would be most critical for the reflectorized material used, the experiment was repeated with 25 subjects for each condition. In this series it was necessary to change the lighting system in order to reduce the angle of viewing. Comparison of the two plans is shown in Sketches A and B of Figure 1.

Since the light units are not comparable in the two series a ratio was used for making direct comparison. The light required for the best Condition 3 was divided into each of the other two. This ratio may be used as a guide to the relative amounts of light needed for discrimination of movement of the train under the three conditions studied.

The results obtained in Series 2 and Series 3 closely parallel with respect to

TABLE 3

COMPARATIVE LEVELS OF ILLUMINATION ON BOXCAR, SERIES 3

Mean and standard deviations for the three experimental conditions

Experimental condition	Units of light - mean*	Ratio of light needed with respect to condition 3 as unity	Standard deviation
Condition No 1	8 33	23.8	2 67
Condition No 2	7.22	20 6	4 29
Condition No 3	35	1 0	12

*Mean score. Score was total of 14 readings for each subject. These are for Series 2 and ratios only are comparable.

ratios as will be noted. Summarized briefly, statistically significant differences were found as follows: (1) In Series 2, measurements the mean level of illumination needed for discrimination of movement in Condition 2 was significantly less than mean illumination required for discrimination of Condition 1 at the two percent level of confidence. (2) For both series the mean illumination for Condition 3 was significantly less than mean illumination level required for Conditions 1 and 2. This was significant at the one percent level of confidence.

TABLE 4

EVALUATION OF DIFFERENCES FOUND, SERIES 3

Values of t for amount of light necessary to determine the direction of motion.

Experimental condition	Value of t
Condition No. 1 Condition No. 2	1 10
Condition No. 1 Condition No. 3	14 87**
Condition No. 2 Condition No 3	8 11**

** Significant at the 1-percent level.

CONCLUSIONS

Subject to the limitations of the experimental procedures, the number of subjects used and other factors which might affect results, the following tentative conclusions may be stated:

1. In general, the hypothesis set forth for experimental testing was confirmed and the use of materials giving greatest brightness-contrast at night significantly decreases: (1) the amount of luminance needed and (2) the difficulty of discriminating movement of boxcars crossing the line of vision at night.

2. The corollary hypothesis that the expanse of reflectorized material has an effect is confirmed. The larger the patches of reflectorized material the lower the level of luminance needed.

3. The extent of the visual angle reflectorized determines effectiveness up to a certain size, but the limits were not determined in this study.

4. It would appear that for a certain area of reflectorized surface of given reflectance characteristics, larger concentrations of reflectorization would be more effective. This study made no attempt to establish optimal values.

APPLICATIONS AND DISCUSSION

Application of the above conclusions to actual highway and driving situations require the basic assumption that the differences found would hold over the wide variation in ranges of distance and illumination which are encountered in driving. Since the experimental conditions show that the materials giving the greatest brightness-contrast and consequent visibility require significantly less illumination for seeing efficiency, there seems to be justification for the assumption.

For comparative purposes only, visibility distances when converted to high-beam headlight intensities are of interest. It is estimated that when using 500 feet as a basis of computation average visibility distance at night under ideal conditions would be approximately: (1) unreflectorized freight train, 425 feet; (2) small reflectorized markers on sill added, 500 feet; (3) fully reflectorized lettering of the type used on the boxcar side, 2,500 feet.[1]

These comparisons are based on relative amounts of light using the inverse-square law. For low headlight beams and conditions of weather giving poor visibility these values would be proportionally lower. The high incidence of automobiles striking the side of trains indicates that many drivers do not see trains at 425 feet.

Since the incident light on the reflectorized materials was not up to the most critical angle, these estimates are conservative and particularly that for Condition 2 as stated. These figures may provide some basis of comparison between the different conditions studied and the

[1] The Overland Route trade mark which was used is more expansive than the small diamonds on the sill.

advantage of the most effective reflectorization.

Further studies need be made of the optimal conditions for size of reflectorized areas, shape of area, spacing distances and height of placement on boxcars for most-effective results.

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