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FIELD EVALUATION OF LOCOMOTIVE CONSPICUITY LIGHTS

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FINAL REPORT

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16. Abstract

Flashing xenon strobe lamps were installed on locomotives in revenue service as a means of alerting motorists to the hazards they are approaching at a rail-highway grade crossing. Effectiveness of these lights in attracting motorists' attention was evaluated. The reactions of both motorists and locomotive crews to the use of strobe lights were also evaluated.

Field observations, interviews, and experiments confirmed the attention-getting value of locomotive-mounted strobe lights used in revenue service to alert motorists and suggested operational procedures and device specifications that are the subject of a separate application guideline report. Experimentation and observation of the strobe lights under railroad operating conditions verified that these lights do not interfere with perception of trackside signals or with normal motorist and crew operations.

The work reported in this document supports a technical recommendation favoring use of strobe lights on more extensive research tests in railroad operational service.

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PREFACE

This report was conducted by the Human Factors Branch, Transportation Systems Center (TSC), as a part of Project PPA-RR409, "Rail Safety/Grade Crossing Protection", sponsored by the Federal Railroad Administration. The TSC Task Manager was R. Coulombre. The observations and tests were in support of a task involving the installation of strobe lights on locomotives and the evaluation of their durability, conducted by Dr. J. Hopkins and A.T. Newfell of TSC, whose continued assistance in all phases of the work was vital to the study. Collection of field data involved the use of locomotives and other property of the Bangor and Aroostook Railroad Company (BAR), and could not have been done without the willing and enthusiastic cooperation of the managing and operating personnel of BAR; in particular, Mr. R.P. Groves and Mr. Frank Larlee. Special thanks are also due to Dr. E.A. Wade of the University of Maine and the students who participated in the field experiment.

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EXECUTIVE SUMMARY

The Department of Transportation's Transportation Systems Center (TSC), sponsored by the Federal Railroad Administration, has conducted a literature review and field studies to evaluate the effectiveness of locomotive-mounted xenon strobe lights in alerting motorists approaching grade crossings.

From the reviewed literature, a set of performance criteria for flashing lights was established, aimed at maximizing the enhancement of train conspicuity while minimizing the likelihood of inducing undesirable side effects.

Three locomotives of the Bangor and Aroostook Railroad (BAR) were equipped with flashing xenon strobe lights and used as lead locomotives in regular road and yard revenue service. The strobes were evaluated through observations and experiments to assess their effectiveness in alerting motorists and to estimate the seriousness of possible adverse side effects.

Observations were made by staff members of the DOT Transportation Systems Center (TSC) and selected additional observers. The appearance of the strobes was observed in daylight, sunset, and at night, from the cab and at various distances up to one-half mile from the locomotive. Check rides were taken in the lead cab of equipped trains. Fourteen train crewmen were interviewed. Provisions were also made for the collection of observations from bus and truck drivers and state patrolmen.

A laboratory experiment was conducted to check the effect of a flashing strobe on the perception of the color of an adjacent signal light. A field experiment was conducted to observe the behavior and to record the comments of subjects who unexpectedly saw the strobes while driving a car toward a grade crossing.

These efforts led to the following conclusions:

1. Flashing xenon strobe lights mounted on a locomotive attract attention to the locomotive.
2. Flashing xenon strobe lights mounted on a locomotive produce no uncontrollable adverse side effects.

The following recommendations are offered:

1. The use of flash tubes giving a high-intensity flash of short duration should be considered as a means of increasing locomotive conspicuity.
2. The operation of flashing strobes on locomotives should be under the control of the engineer.
3. The strobes should be operated at 800 candelas effective intensity at night and 4,000 candelas in the daytime.
4. The rear thirty degrees of the strobe beam should be masked out.
5. Additional studies should be conducted to check the effects of prolonged crew exposure to strobe backscatter from fog and snow, to check the effects of an 800-candela strobe on motorists under extremely dark ambient conditions, and to compare the strobes with alternative conspicuity light systems.

1. BACKGROUND AND APPROACH

1.1 OBJECTIVE

The objective of this project was to evaluate the effectiveness of flashing xenon strobe lights mounted on railroad locomotives as a means of attracting the attention of motorists approaching railroad-highway grade crossings.

1.2 DEVELOPMENT OF REQUIREMENTS

Active warnings and barriers at grade crossings are known to be effective means for causing automobiles to stop safely clear of a grade crossing when a train is approaching or occupying the crossing. However, as of 1972, only 22 percent of public grade crossings had active protection; the balance, nearly 175,000 in number plus some 140,000 private crossings, rely on signs and highway markings (or no warning at all) to alert drivers to the potential hazard. Since both financial and time constraints prevent any significant early correction of this situation, other protective countermeasures have been sought.

An attractive alternative to instrumenting crossings is to instrument the trains, since the hazard exists only when the train approaches and occupies the crossing and since there are only 15 percent as many locomotives as public crossings. This concept is not new; audio-visual warnings (bell, whistle, horn, headlights, etc.) have long been standard equipment on locomotives. However, the number of car-train collisions regularly occurring in spite of such devices points up the potential value of enhancing the present systems.

The apparent difficulty in hearing and seeing trains at or near crossings was verified in a study sponsored by the Federal Railroad Administration (Aurelius and Korobow, 1971). As a result of both literature review and laboratory and field tests, the authors included in their recommendations the use of "...two omnidirectional xenon strobe lamps mounted on the cab roof near each side of the locomotive. They should be provided with a switch to give high intensity in daylight and lower intensity at night. They should flash alternately when the train is moving and simultaneously at a lower rate when it is standing still." (p. 19). Reasons for selection of xenon strobes included wide-angle conspicuity and the attention-getting value of a bright flash of light. Xenon strobes were considered superior to incandescent lamps "...because they can provide a very quick, high-intensity, omnidirectional flash without moving parts... (and are) ... reputed to be superior to incandescent lamps in penetrating haze and fog." (p. 20). A subsequent study, (Sanders et al., 1974), evaluated cab-mounted xenon strobes against an experimental beacon, clearance lights, fluorescent panels, and the standard headlight. Although behavioral measures (judgment of safety margin, judgment of time of arrival of train at crossing) failed to show any superior system, the subjective ratings of effectiveness by 35 subjects clearly favored strobes for use at night.

As a result of these findings, further evaluation of locomotive-mounted strobe lights was included in the FRA-sponsored program on grade-crossing safety conducted at the Department of Transportation's Transportation Systems Center (TSC), to include the installation and evaluation of xenon strobe lights in a fleet of operating locomotives. This report summarizes the human factors support provided at TSC for that effort.

1.3 APPROACH

Human factors support for the TSC program of evaluation of conspicuity lights included consideration of the literature relevant to the problem, advice and assistance in the collection of observations, and the performance of two experiments aimed at amplifying or verifying available information.

Section 2 of this report reviews the published literature for its implications for the selection and use of conspicuity lights. The discussion is in terms of eight parameters whose influence on the utility and safety of conspicuity lights must be taken into account in the selection of light systems. Section 3 summarizes the results of programmed observations of the lights and interviews with train crew members who had observed the lights during revenue operations. Provisions for obtaining general reactions from the public are also described. Section 4 summarizes two experiments. The first was a laboratory study conducted to ascertain whether xenon strobes on locomotives might be expected to interfere with the perception of nearby trackside signals. The second was a field experiment to check the reactions of automobile drivers unexpectedly exposed to warning light signals on a locomotive. Section 5 summarizes the conclusions from this support activity and presents recommendations derived from the findings.

2. LITERATURE REVIEW

2.1 VISUAL WARNING SIGNAL PARAMETER DESIGN VALUES

Initial recommendations for the selection of flashing lights were derived from the relevant literature. The parameters of concern were light type, flash frequency, flash duration, arrangement, usage, beam size, brightness, and color.

A major tradeoff influenced the determination of parameter values. The more attention-getting a lighting system becomes, the more distracting it can be. On one hand, it is desirable that conspicuity lights be unique, possibly even startling in appearance, to gain and hold the attention of a driver approaching a crossing. On the other hand, it is undesirable for conspicuity lights to be so distracting that they interfere with the safe performance of duties and activities of railroad personnel working in their vicinity, or that they seriously annoy nearby residents. The criteria for selection of recommended parameter values were that they attract an approaching driver's attention, inform the driver of the associated hazard, but <u>do not</u> interfere with the safe performance of train operation by the train crew, yard and maintenance work by other railroad crews, or automobile operators on highways close to the railroad.

The recommended values or range of values of the eight design parameters are summarized in Table 2-1, which is followed by a discussion supporting the recommendation for each parameter. These recommendations were selected on the basis of information published in the literature, and with the trade-offs in attention-getting characteristics kept in mind. The recommendations were intended to provide guidelines rather than firm specifications for the systems designer, since they did not take into account the technical, economic, and political feasibility of employing these values.

TABLE 2-1. RECOMMENDATIONS FOR TRAIN CONSPICUITY LIGHTING DERIVED FROM HUMAN FACTORS LITERATURE

No.	Parameter	Recommendation
1	Light Type	Flashing lights, preferably xenon strobe
2	Flash Frequency	1-3 Hz, certainly no more than 5 Hz
3	Flash Duration	Not greater than 0.1 second per flash
4	Arrangement	Standardized separation of roof mounted pairs flashing in unison
5	Usage	On only at grade crossings with high/low intensity switch
6	Beam Size	Horizontally: 180° Vertically: at least 2° and probably 5° down
7	Brightness	By day, 4,000-10,000 candelas; reducible by a factor of ten-to-one-hundred with a high/low intensity switch
8	Color	Unfiltered xenon strobe

2.2 LIGHT TYPE

The problem in selecting the general type of lighting system for train conspicuity is to choose the one most able to attract involuntary attention; i.e., to eliminate the need for active visual search by appropriate stimulation of the peripheral visual field. The search for a particularly noticeable light source for accident prevention has been undertaken by other transportation agencies: by the U.S. Coast Guard for the detection of buoys, markers, and other vessels (Blaise and Petry, 1960; Sirkis and Gerathewohl, 1972); by the Federal Aviation Administration, primarily for the early detection of other aircraft (Gerathewohl and Strughold, 1953; Gerathewohl, 1953; Gerathewohl, 1957; Gerathewohl et al., 1970; Paaninen, et al., 1969); by the Federal Railroad Administration, for the enhancement of train visibility to prevent rear-end collisions (Hopkins, 1973); and by the British government, for automotive applications (Gibbs *et al.*, 1955).

For the U.S. Coast Guard a study of seven different light sources was conducted at distances of up to 10,000 yards over water (Sirkis and Gerathewohl, 1972). Tests of detection range, peripheral detection (from 15^{o} to 60^{o} off axis), detection range and color recognition, brightness matching, and subjective ranking are reported. The results are summarized in Table 2-2. Rank orderings by sixteen subjects place the single-flick flashtube as first or second in all cases. The light signal used had a flash duration of 14 microseconds, a flash rate of one per second, and an integrated intensity of 46.5 candela-seconds.

Work performed for the Federal Aviation Administration concerns the problem of making one aircraft more visible to another. The effectiveness of signals for warning purposes has been termed "conspicuity" (Gerathewohl, 1953), referring to the "attention-getting" properties of visible signals. "Conspicuity is measured by the speed with which response is made to a light, when the observer is engaged in a complex task and does not know when to expect the light to appear." (Gerathewohl, 1953, p. 568). Tests comparing steady versus flashing lights at low contrast levels, as might be encountered in daylight, demonstrate that flashing lights have a greater conspicuity than steady signals (Gerathewohl, 1953; Gerathewohl, 1957; Gerathewohl et al., 1970). The explanation offered is that the eye is more sensitive to the change or on-off characteristics of the light than to the continued presence of the light itself (Gerathewohl, 1953; Gerathewohl, 1957). This explanation is supported to varying degrees by other, more basic literature (Anglin and Mansfield, 1968; Bartlett and White, 1965; Boynton and Siegfried, 1962; duMas, 1970; Long, 1951; Nachmias and Steinman, 1965; Wasserman, 1966). Finally, a NASA Technical Note (Paaninen et al., 1969) strongly endorses xenon flashlamps as part of an optical pilot warning indicator system.

TABLE 2-2. RANK ORDERS OF LIGHT TYPES BY SIXTEEN SUBJECTS

Light Type	Rank Order				
	Detection Range	Peripheral Detection Range	Detection Range and Color Rec	Brightness Matching	Subjective Ranking
1. Single-flick Flashtube	1	2	2	1	1
2. Tri-flick Burst Flash-tube	3	3	4	3	2
3. Pent-flick Burst Flash-tube	6	4	3	7	6
4. White Flashing	2	5	5	6	5
5. Red, Flashing	4	6	1	4	4
6. Green, Flashing, Low Saturation	5	1	7	5	3
7. Green, Flashing, High Saturation	7	7	6	2	7

Work for the Federal Railroad Administration has also revealed similiar results in support of a flashing lamp as the most desirable of various visual devices considered for making the rear of a train more visible or noticeable (Hopkins, 1973).

Two field studies have compared the performance of various lighting systems mounted on locomotives. Observations for the first (Aurelius and Korobow, 1971) were made in daylight and from twilight into darkness. Observers were to judge the effectiveness of the various devices. A direct summary of their results (Aurelius and Korobow, 1971, p. 48) follows in Table 2-3.

TABLE 2-3. OBSERVATIONS OF THE EFFECTIVENESS OF VARIOUS LIGHTING SYSTEMS

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1. Prime Manufacturing Corp., Oak Creek, Wisconsin: Model 8900. This light uses three 75 watt sealed-beam lamps which are flashed sequentially to simulate rotation without moving parts. This device was judged poor in daylight because the fixed-position lamps did not provide full brightness at all angles. An observer not positioned in just the right spot did not receive visual impact.

2. Pyle 15360 'Roof Gyralite'; Trans-Lite Inc., Milford, Connecticut. This light has a sealed-beam lamp in its upper dome, which is aimed down on a wedge-shaped reflector which is rotated. It provided good visual impact in daylight.

3. Safety Products Co., Chicago, Illinois. No model number. A strobe lamp, using a thin ring-shaped flash tube concentric with a reflector that resembles two cones stuck together at the apexes. The light output of this unit was too small to be effective in daylight.

4. Western-Cullen Division, Federal Sign and Signal Corp., Chicago, Illinois: Model D-312. Two 75 watt sealed-beam incandescent lamps mounted back-to-back and rotated by a motor. This lamp was not tested at Essex, but it was examined and judged likely to be effective in daylight.

5. Whelen Engineering Co., Inc., Deep River, Connecticut: Model RB-11. This device uses a light bulb with three magnifying lenses arranged around it and rotated. The light output of this unit was too small to be effective in daylight.

6. Whelen: Model 2700 Dual Strobe. Two high-output strobe lamps, which for the evaluation were mounted one on each side of the cab roof. The manufacturer claims 1,000,000 candlepower, and these were the best performers of all lamps tested in daylight.

TABLE 2-3 - Continued

7. Whelen: Model 2500 Dual Strobe. Similar to the 2700 but smaller. Very good visual impact in daylight.

8. Whelen: Model 2800 Dual Seal Beam Strobe. The strobe tubes of this unit are mounted in separate sealed-beam reflectors looking something like automobile foglights. These make no claim to cover all angles and were not compared with the other units. Their on-axis output is very high. (Aurelius and Korobow, 1971, p. 48)

The Pyle 15360 'Roof Gyralight,' the Western-Cullen Model D-312, and the Whelen Dual Strobes (both models) all rated well. These well-rated lights were flashing lights of either a rotating beacon or flash tube type. The Whelen Strobes were said to be the best performers.

The other field study (Sanders et al., 1974) revealed little differentiation among six lighting systems in terms of actual performance measures (last gap acceptance time and estimated arrival time at the grade crossings). A slight trend for train speed to be underestimated at night in the presence of the Whelen Strobe was noted. Subjective ratings, however, did place the Whelen Strobe as best for night conditions, followed, in order, by the Bicolor Radial Beacon, Grimes Strobe, yellow clearance lights outlining the engine, fluorescent panels, and the standard locomotive headlights (Sanders et al., 1974, p. 18). Daylight ratings were not at all conclusive.

The pattern of these studies concerned with the conspicuity, visibility, or noticeability of visual signals strongly supports the use of flashing over steady lights, especially xenon as opposed to incandescent (Paaninen et al., 1969, p. 10), as the best potential for an inexpensive, retrofitted, cab-mounted device for enhancing visibility at grade crossings.

2.3 FLASH FREQUENCY

Two problems combine in the selection of a flash frequency. The first is to find the most conspicuous frequency. Gerathewohl, in a series of studies seeking an optimal airborne visual warning system (Gerathewohl and Strughold, 1953; Gerathewohl, 1953; Gerathewohl, 1957; Gerathewohl et al., 1970; and Sirkis and Gerathewohl, 1972), concluded that:

> Experiments with steady and flashing lights have shown that under operational conditions the most conspicuous signal is one which flashes about two or three times per second...(Gerathewohl et al., 1970, p.1).

Another study (Aitken et al., 1963) concerned with aircraft visibility sought the frequency most positively rated by ten observers. The highest preference went to the two lowest frequencies tested (1.00 and 1.33 flashes per second).

The results of a third study (Matin, 1962) suggest that better peripheral visual field responses are obtainable at frequencies greater than 10 Hz, but the adverse effects possible at such frequencies (discussed below) rule this range out.

Consequently, the most conspicuous frequency must lie in the region from 1-3 Hz, but an exact value is indeterminable on the basis of present information. The results of the first series of studies discussed above were obtained under operational conditions, while the second (Aitken et al., 1963) was a laboratory study. Therefore, there may be an outdoor, "operational" condition requiring the slightly higher flash frequency of from 2-3 Hz for best conspicuity.

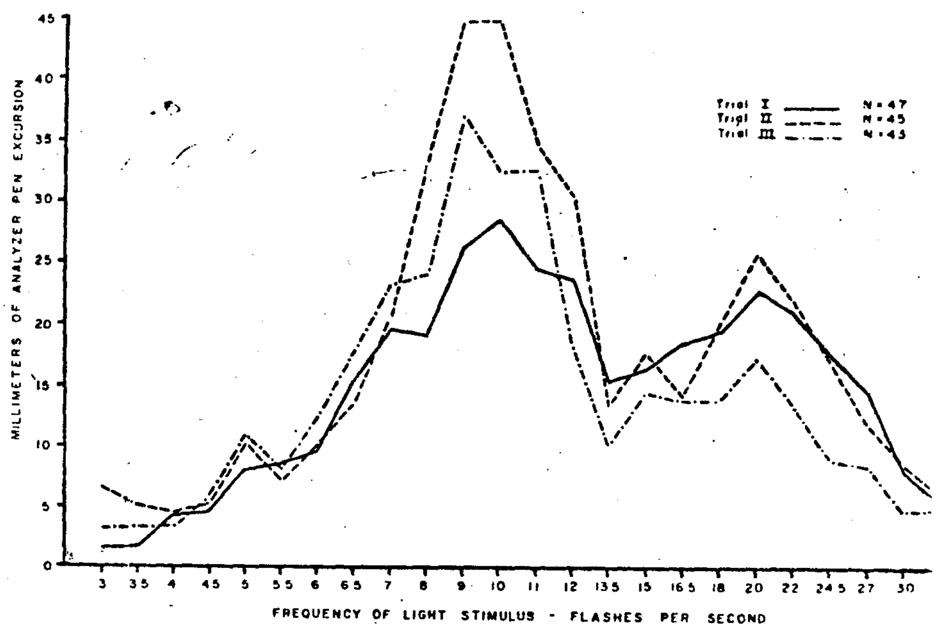
The second problem in selecting flash frequency is to avoid inducing adverse physical reactions in either the railroad employees or the general population of drivers or residents in the vicinity of these lights. It is known that intermittent illumination may induce the following:

> ...nausea, vertigo, visual hallucinations, headaches, ocular discomfort, and drowsiness; these responses being

encountered in a rather small percentage of persons. Severe reactions are found in about 5 percent of known epileptics, the total epileptic population constituting about ¼ percent of the general population. (Alexander and Chiles, 1959, p. 1; see also Walter, 1963, p. 100 and Aitken et al., 1963, p. 305).

A physiological correlate of these effects, a high-amplitude slow wave in the electroencephalographic wave pattern (EEG) known as photic driving, has been induced by flashes at frequencies as low as 6 Hz with a peak at 10 Hz. (Grossman, 1967, p. 680; also see Figure 2-1, reproduced from Ulett and Johnson, 1958, p. 158).

One study (Ailslieger and Dick, 1966) has found real effects of flashing lights (5 Hz) on at least one perceptual-motor skill. Reaction time, digit span, pursuit tracking, and a complex task of all three combined were tested. Performance was found to be slightly degraded on the pursuit tracking task in the presence of a flashing light.



Courtesy: Ulett and Johnson, © 1958. Williams & Williams Co., Baltimore.

Figure 2-1. Stability of Photic Driving. Median Driving Responses of Three Trials

In short, although only a few people are seriously affected by flashing lights, one upset driver or engineer could cause a serious accident. Therefore an upper limit of 5 Hz is recommended for any conspicuity lighting system, and still lower frequencies are preferred.

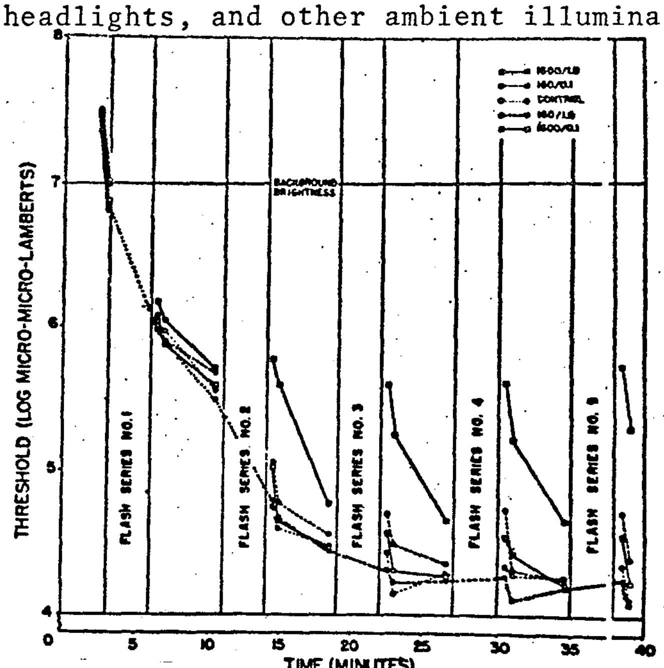
2.4 FLASH DURATION AND CONTRAST

Conspicuity, as measured by the response time to a signal, is not entirely correlated with the effective intensity of the signal. The experiments noted in Section 2.2 demonstrate that flashing signals are more conspicuous than steady signals of the same brightness and that, for durations exceeding 0.1 sec., the shorter the flash duration the more conspicuous it is (Gerathewohl et al., 1970, p. 1). Long, 1951, supports these same findings for flash stimuli presented 15 degrees into the peripheral visual field. The flash duration for xenon strobe lights is stated to range from 0.1 to 1.0 msec (Paaninen et al., 1969, p. 9), well below the 0.1 sec duration for which conspicuity is the same for all flash durations (Gerathewohl et al., 1970, p. 1).

Laboratory studies (Gerathewohl, 1953) reveal little difference between the conspicuity of flashing and steady lights when the light is twice (or more) as bright as the background (see Section 2.8), suggesting that flashing lights would be most effective for day use.

However, for night use, the problem of severe disruption of dark-adaptation must be considered. In general, some 45 minutes are required for the eye to reach maximum sensitivity in total darkness. Recovery from disruption of this process requires restabilization of at least two processes: neural and photochemical (Boynton in Rosenblith, 1961). Wald and Clark (1937) have shown that the photochemical process consists of two possible sub-processes; one requiring a considerably longer time than the other for restabilization. The longer process is induced by a long exposure, low-intensity flash in contrast to the short recovery time after a short duration, high-intensity flash such as that produced by a xenon strobe flash of about 1 msec duration.

The results of three studies indicate the restabilization duration resulting from both the shorter photochemical process and the neural process. Figure 2-2 (Grant and Mote, 1949) compares the normal course of dark-adaptation with the threshold responses to five flashes of 1600 millilamberts and 160 millilamberts with durations of one second and one-tenth second. It was concluded that recovery was great enough to compensate for the flashes within 30 seconds except for the 1600 millilambert-1.0 second flashes. A further study (Suchman and Weld, 1938) supports these findings in general. A third study (Adams et al., 1955) reports only slight changes in the dark-adaptation threshold for the shortest flash duration used, (15 millisec.) the closest value to that of a xenon flash tube (1.0 msec) in the studies reviewed. The available evidence suggests that because of both the point source size of the xenon strobe lights and the very short flash durations possible, no hazardous shifts in the dark-adaptation level should be expected. Certainly the locomotive headlight, the automobile headlights, and other ambient illumination will be



Courtesy: Grant and Mote. © 1949 by the American Psychological Association.

Figure 2-2. The Course of Dark Adaptation Under the Experimental and Control Conditions. Threshold (in log μμl) is Plotted Against Time (in min.) for Each Procedure more disruptive. (Factors such as brightness and atmospheric scattering are also involved and will be discussed in Section 2.8.) Therefore, due to both the minimal effects of the short-duration, point-light flashes on dark-adaptation level and the unique warning nature of a flashing signal at night amid many steady lights, the use of flashing xenon strobe lights is also warranted at night.

One other problem is the fading of lights in the peripheral visual field. It is known that peripherally presented lights tend to fade out (Troxler's Effect) (Goldstein, 1968; Kirkwood, 1968; Poe and Crovitz, 1968). However, the flash durations for the recommended xenon flashing strobe lighting system are so short and of sufficiently high frequency that this type of interference with perception in the peripheral visual field could not occur.

2.5 ARRANGEMENT

The appearance of a xenon strobe light as a point light source (Gerathewohl et al., 1970, p. 1), except for atmospheric scattering, makes it very conspicuous; however, "... point sources are judged as being at a greater distance than they really are." (Aurelius and Korobow, 1971, p. 39). A paper reviewing the sources and prevention of grade-crossing accidents notes that depth perception at the distances involved in grade-crossing approaches "... depends upon the observer estimating from a known dimension on the perceived object." (Aurelius and Korobow, 1971, p. 39). Consequently, the authors recommend paired roof lights that flash alternately, preferably at a rate proportional to the train speed. This arrangement places the flashing lights apart at a fixed learnable distance at the highest position atop the locomotive cab roof. Because visual resolution (Kerr, 1971) as well as the ability to make distance comparisons between two stimuli (Matthews, 1969) deteriorates in the peripheral visual field, the lights should be placed as far apart as possible. They should outline the outer edges of the cab, providing cab-edge contour. This is considered a major information requirement for driver's estimation of the dynamic characteristics of motion (Finch, 1959, p. 16). In conclusion: "... as pairs they (would) serve to alert viewers by apparent movement, extreme effectiveness of light output and wide angle of view." (Aurelius and Korobow, 1971, p. 40).

Another factor in the estimation of distance from separated lights prompted a more recent recommendation that the lights flash in unison (Hopkins, 1973, p. 33). This arrangement of synchronous flashing lights eliminates the need for the viewer remembering the position of the previous flash on a moving locomotive. The difficulty of such a task is most pronounced when the between-lights flash interval exceeds 0.20 second (Leyzorek, 1951, p. 364; see also King, 1965), which is less than the interflash interval already recommended (see Section 2.3).

Consequently, it is recommended that pairs of xenon strobe lights be mounted at a standard distance as far apart as is consistently possible on the lead locomotive cab roof, and that they flash in unison.

2.6 USAGE

A lighting system for locomotive-mounted grade-crossing warning can be used in either of two ways: continuously on, or turned on only prior to a grade crossing and then turned off immediately after passing through. There are a number of arguments for the latter usage scheme.

Choice of intensity for a continuously-on grade-crossing warning system is bounded between the high intensity required for optimal warning effectiveness and the highest level which is tolerable to the engineer or the nearby automobile driver or resident. Tests to determine this optimal intensity have been suggested (Aurelius and Korobow, 1971, p. 21) along with the addition of a high/low intensity switch for the engineer's use (Aurelius and Korobow, 1971, p. 46). However, if the flashing strobe lights are used only at grade crossings, then the control of brightness becomes more important for penetrating adverse weather conditions. These topics are discussed in Section 2.8, which states an appropriate intensity level and argues further for the use of a high/low intensity switch.

Section 2.3 dealt with possible adverse physical reactions to intermittent illumination and recommended frequencies that would be least troublesome in this regard. The comments of the locomotive crews involved in two separate studies using roof-mounted flashing lights confirmed the possibility of such reactions. In the first (Aurelius and Korobow, 1971), a general study of visual and auditory warning devices for grade-crossing protection, it is reported that:

> ... complaints have been made by crews of locomotives that have roof lights, about the annoyance caused by the flashes of light reflected from objects near the right-of-way. (Aurelius and Korobow, 1971, p. 21).

The second (Sanders et al., 1974), an evaluation of five candidate grade-crossing warning systems, similarly notes:

> Both the Whelen and Grimes Strobes tended to bother normal vision making it difficult for the engineer to locate the brakeman or for the brakeman to view the locomotive. These objections were mild, however. (p. 46).

These adverse effects can be minimized by using the frequencies recommended in Section 2.3 (see also Aitkin, 1963, p. 305), and by using the lights only at the grade-crossings. In addition, this latter solution would conserve energy and enhance the meaning of the flashing lights as a warning of approaching danger.

2.7 BEAM SIZE

No literature offering any guidelines for this factor was available. However, since the angle of approach of locomotive and automobile to the grade crossing can vary considerably, a horizontal beam of at least 30 to 60 degrees or better would be appropriate for a track radius of curvature of ¼ to ½ mile (Hopkins, 1973, p. 33). In short, a horizontal beam as wide as possible should be employed, so long as it remains forward of the locomotive's movement. The vertical dimensions are determined by the height of light placement above the ground, obstructions, and the distance required for adequate warning. A required 20-25 second constant warning time, or slightly over 1,000 feet, has been proposed (Hopkins, 1973, p. 2). Lights mounted on top of the cab (about 15 feet up), without obstruction, should be aimed at least 2 degrees down from horizontal or, preferably, 5 degrees to reach the proposed warning distance (Hopkins, 1973, p. 33).

2.8 BRIGHTNESS

Except for the interactions with flash duration noted in Section 2.4, the conspicuity of a light is directly related to its brightness. However, an excessively brilliant light is wasteful of energy and may be glaring or blinding particularly to the dark-adapted eye at night. This problem is further accentuated if the light must be bright enough to penetrate fog, rain, or snow to provide adequate warning time (about ¼ mile (Hopkins, 1973, p. 2)).

A minimum brightness value for detection of a point source of 180-msec flash duration in a completely darkened laboratory situation involving virtually no atmospheric attenuation or interference is about 0.2 candelas for "... semi-trained subjects who have large and ill-defined solid angles to search." (Wienke, 1964, p. 310). But this value is a bare minimum for optimal contrast and transmissivity conditions. More realistic intensity values for a point source must incorporate atmospheric attenuation over ¼ mile. The following values have been proposed: for clear, daylight conditions 3,800 candelas, and for clear, night conditions 0.8 candelas (Hopkins, 1973, p. 52).

An international symposium on the perception and application of flashing lights was held at Imperial College, London, under the joint auspices of the National Illumination Committee of Great Britain and the Applied Optics Section, Imperial College, on 19-22

April 1971. The published proceedings of this symposium (Anon., 1971) constitute an up-to-date review of the topic; unless otherwise cited, the following discussion is based on material in that volume.

Very generally, if a steady light is interrupted to produce long-duration flashes, the flashes appear as bright to an observer as the steady light. That is, the effective intensity of the flash (I_e) equals the steady intensity (I), or $I_e/I = 1$. If we now progressively shorten the flash duration (t), below a critical duration (t_c) the flash appears successively dimmer. Bloch's Law states that below t_c the effective intensity depends on the product of intensity and duration, regardless of duration. That is, a short, intense flash will appear as bright as a longer, less intense flash, and $I_e/I = kt$, where k is an arbitrary constant. Blondel and Rey combined these two relationships into a single function of the form $I_e/I = t/(a+t)$ where a is a constant. When t is very large with respect to a, the equation approximates the steady light condition; when t is very small with respect to a, the equation approximates Bloch's Law, with $k = 1/a$. Many experiments with lights at threshold levels have yielded a value of the Blondel-Rey constant, a, of about 0.2, which is generally used for practical evaluation of light sources. Threshold studies have yielded a value of t_c at about 0.1 second. This value decreases for higher intensity flashes.

At flash intensities well above threshold, a phenomenon known as the Broca-Sulzer effect occurs. With very short-duration flashes, (0.03 to 0.1 second) the brightness appears to be greater than that of an equally intense steady light (up to five times as bright). The reason for this effect is not known, although it has been attributed to the "on effect", a brief physiological enhancement of neural responses following the onset of a stimulus. The effect seems to occur at flash durations just above t_c, the critical duration decreasing with increasing flash intensity. The Broca-Sulzer effect has not been mapped accurately enough to determine whether the strobe lights evaluated in the present study produce the effect.

It should be noted that the Broca-Sulzer effect is not the same as the advantage in luminous efficiency of short flashes. For practical purposes, the foregoing relationships show that, for a given expenditure of energy (It), the greatest effective intensity is obtained from a flash of high intensity and short duration (any duration less than t_c). This advantage in efficiency of luminous output will be offset if more energy is used to achieve the output in the short flash (Douglas, 1957). Fortunately, the data of Hopkins (1973, p. 31, Table 3) suggest that xenon strobes take advantage of this effect, since their power requirements are similar to those of competing incandescent lamps with flash durations in excess of t_c.

The factors affecting the effective intensity of flashing lights are summarized graphically in Figure 2-3. Note that calculations using the Blondel-Rey equation are conservative (underestimate apparent intensity) in the vicinity of the critical duration, both because the theoretical curve fits real data most poorly in this region and because the Broca-Sulzer effect (if present) is not taken into account.

Any light observed at some distance is affected in appearance by the intervening atmosphere. Allard's Law shows the illuminance at a given distance (d) from a source of intensity (I) as a function of atmospheric transmittance (T), thus:

$$E = IT^d/d^2.$$

Using for E a measured threshold at which light can just be perceived, Allard's Law can be used to predict the distance at which a light of a given intensity will just disappear, as a function of atmospheric conditions. Figure 2-4 applies Allard's Law to provide a useful set of curves for determining visible threshold range for daylight vision (E = 1,000 mile-candelas) as a function of meteorological visibility. To evaluate a flashing light with Figure 2-4, use I_e for intensity (I), as calculated by the Blondel-Rey equation.

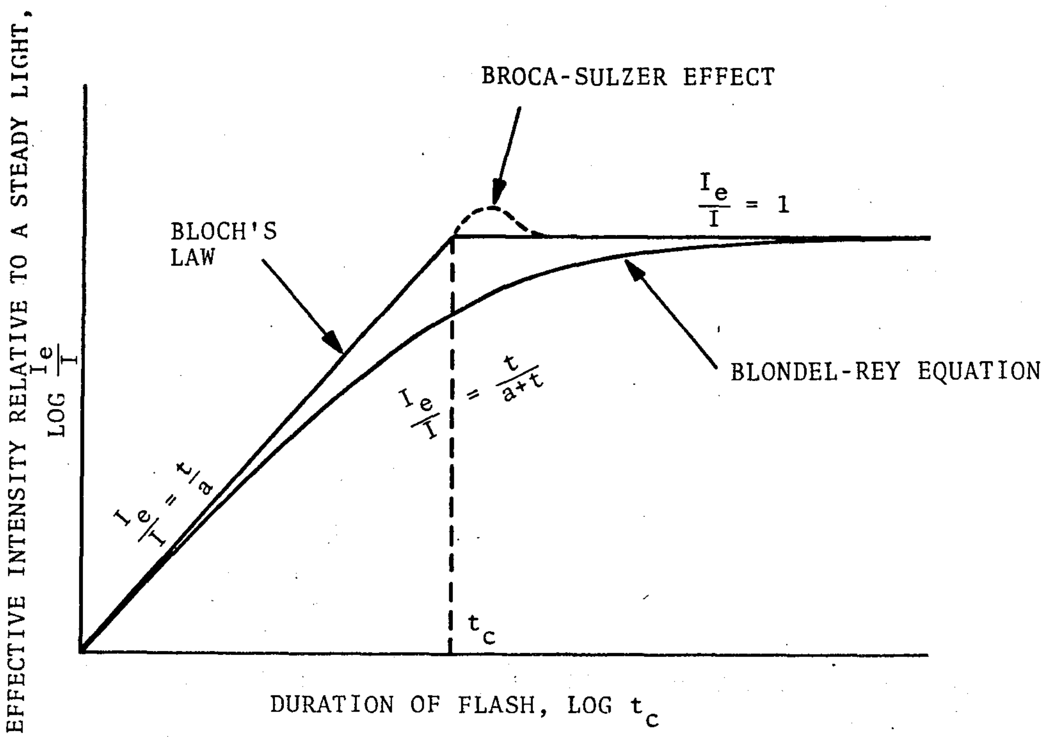


Figure 2-3. Factors Affecting Apparent Brightness of Flash (Log Scales Used to Accentuate Small Values)

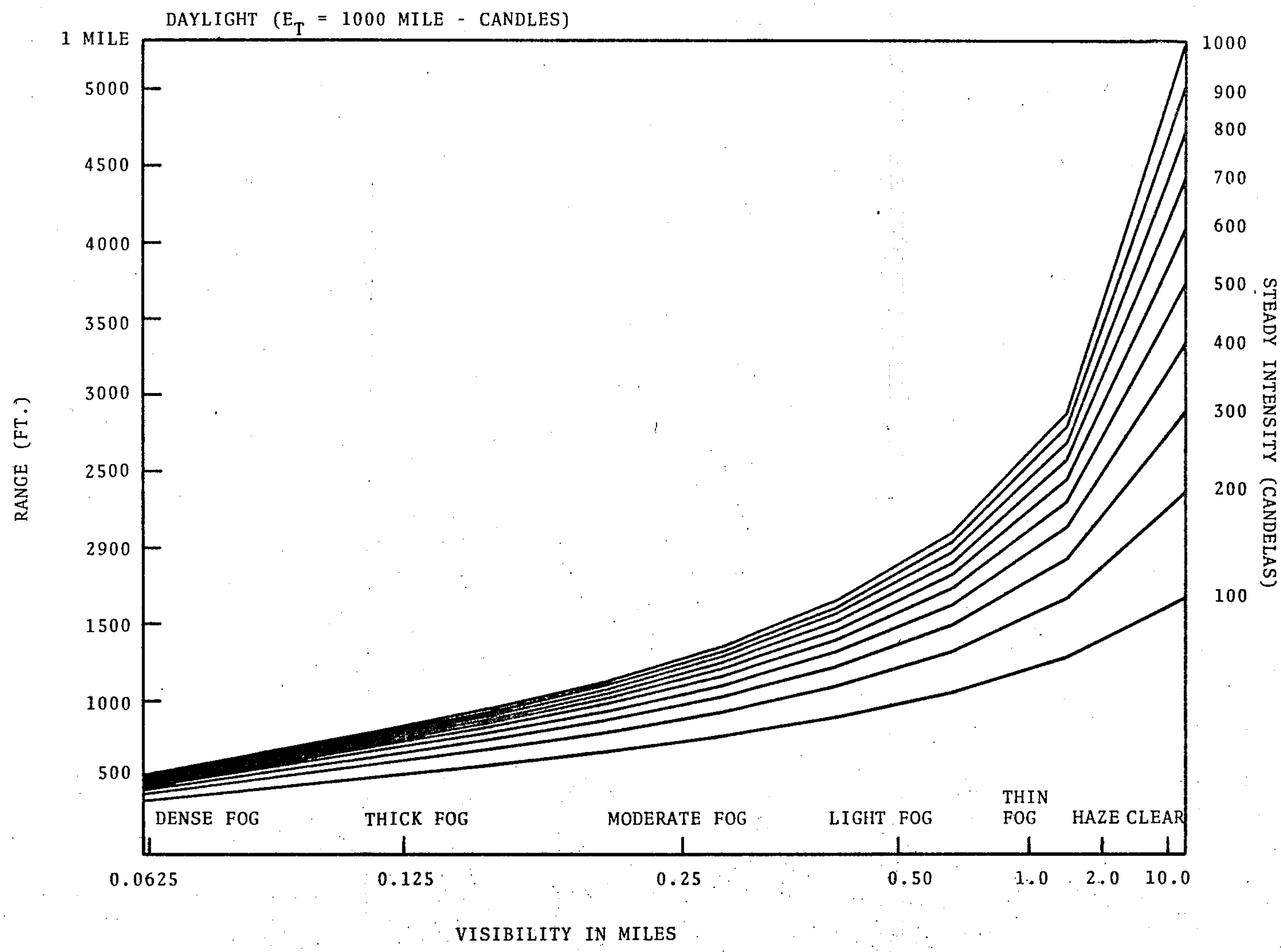


Figure 2-4. Visibility of Lights as a Function of Atmospheric Visibility

Any value selected for daytime conspicuity risks being far too bright for night use. Therefore, provision for two brightness levels is highly recommended for operational use. A study of highway lighting in fog conditions confirms the usefulness of such a choice for brightness reductions of up to 1/100th (Finch, 1961, p. 28).

The responsiveness to peripheral visual stimuli is also directly related to brightness. Fortunately, it has been found that for the dark-adapted eye "... the same stimulus appears brighter in the periphery than in the fovea..." (Marks, 1966, p. 340). The previous discussion is based solely on foveally presented stimuli. This enhancement implies a further minimization of the difficulties of peripheral visual field detection of this warning signal in night conditions.

A study of warning lights (Hopkins, 1973, p. 33) to mark the rear of trains explored the same brightness and atmospheric attenuation and interference problems and recommended 4,000 to 10,000 effective candelas, with provision for a brightness switch permitting reduction by a factor of ten to one hundred at night.

2.9 COLOR

To convey a sense of danger to an operator, visual signals are often made red. Red signals have been found to be more visible for a wide range of atmospheric attenuation and interference conditions (Wulfeck *et al.*, 1958, p. 240-241). However, unless the most efficient source of light for the signal happens to be red, the color of the light is obtained by filtering out of the source all wavelengths except a red band, generally at a considerable cost in energy. It is this energy which contributes to the brightness of the signal — a more important factor in its transmission over long distances through atmospheric interference.

For increased detection of warning lights in the peripheral visual field, it would seem that color spectral bands for which the periphery is most sensitive should be used. The peripheral region from 25 to 40 degrees from the fovea is most sensitive to narrow spectral bands of first red, then successively, yellow, green, and blue (Marks, 1966, p. 335). However, a xenon strobe has a relatively flat spectrum in the visual range (400 to 700 nm) (Paaninen et al., 1969, p. 35), covering all sensitive color bands equally, though not additively (Guth, 1965, p. 722), and giving light of a bluish-white appearance. Since color coding such a signal would be highly inefficient from the point of view of energy expenditure, it might result in a signal with poorer transmissivity through fog, rain, or snow (Marsh, 1957, p. 626), and is redundant to flashing as a danger code, the recommendation for a conspicuity lighting system is an <u>unfiltered</u> xenon strobe (Hopkins, 1973, p. 33).

3. OBSERVATIONS

3.1 INTRODUCTION

The human factors field work was in support of an operation involving the installation of strobe lights on three locomotives on the Bangor and Aroostook Railroad Company (BAR) and observing their appearance during routine yard and road freight operations over a period of approximately three months. The lights were Whelen Xenon Strobes, Model 2700, rated at approximately 800 candelas effective intensity. A clear lens cap produced a 360-degree horizontal beam, but of relatively small vertical beam-width, with a bluish-white hue. Each light produced a flash of less than one millisecond duration at a rate of one per second (1 Hz). On each locomotive, two lights were mounted close to the leading edge of the cab roof and close to the sides, with about nine-to-ten feet separation, depending on locomotive model. From the side, only one light was visible because of the slope of the cab roof. On each cab, the two lights were one-half second out of synchronization, producing alternate flashes at a combined rate of 2 Hz. These specifications were considered to be a reasonable compromise between the recommendations derived from the literature (Table 2-1) and what was readily available in the market.

The observations were planned to estimate (1) the effectiveness of the strobes in gaining the attention of approaching motorists, and (2) the presence or absence of side-effects that might interfere with the duties of train crews and yard crews, cause difficulty for drivers on adjacent highways, or annoy nearby residents. To assure some consideration of factors judged to be potentially critical, arrangements were made for a strobe-equipped locomotive to be available under specified conditions and for TSC staff members and other selected observers to make programmed observations. BAR train crew members were interviewed to sample their observations during daily use of the lights.

Arrangements were also made to obtain reactions from the general public after the lights had been in operational use for some time.

3.2 PROGRAMMED OBSERVATIONS

(1) Yard Observations. Preliminary observations were made to eliminate the possibility of serious side effects before putting strobes out on the road. Observations of a strobe-equipped locomotive operating in the BAR classification yards at Northern Maine Junction were made in clear weather during the day, looking into the setting sun at dusk, and at night with a three-quarters moon. Observers included two TSC staff members, a professor of psychology from the University of Maine, a trooper of the Maine State Police, and a representative of the Maine Department of Transportation. Observation distances ranged from within and beside the cab to one-half mile.

Under all conditions the strobes were unanimously judged to be readily visible and attention-getting. Detection of the strobes in peripheral vision was checked by two observers; the pulsation could be detected as far as 90 degrees off the visual axis. The state trooper did not consider that the strobes would interfere with driving an automobile on an adjacent highway at night, commenting that highway snowplows are equipped with brighter strobes. The flashing lights did not cause any difficulty for those walking beside the locomotive at night; in fact, the light of a small flashlight was adequate to mask out the strobe reflections effectively. The train crew reported no interference with their duties, although they noted that there was a continual awareness of the flashes.

On another occasion, two TSC staff members observed a strobe-equipped locomotive at a distance of 1,100 feet during a moderate-to-heavy afternoon snowstorm. The mass of the locomotive was barely discernible, with no detail visible, but the strobes were clearly visible. The headlights were also visible but were judged to be far less effective for gaining attention.

(2) Road Observations. TSC staff members rode lead locomotives on six regular freight runs, observing the behavior

of drivers at crossings and of the crew at work. On one daylight run in a locomotive without strobes, several incidents of questionable driver behavior (such as crossing just ahead of the train instead of waiting) were observed. Two weeks later, on a strobe-equipped locomotive on the same run, no such incidents were observed. However, traffic happened to be much lighter on the second run. Crew members frequently commented to the effect that a particular car would not have stopped if they had not had the strobes. These observations are impossible to verify but are indicative of the enthusiastic acceptance of the lights by the crewmen (see Section 3.3).

During the day, the strobes were not detectable in the cab. At night, the hood, the bell, and the handrails reflected highlights into the cab, but with no interference with crew duties. On looking back from the cab at night to check for hot boxes, one was very aware of the flashing light, but there was no interference with visual observations. Foliage and snow banks gave considerable reflection, as did reflective highway signs and license plates (advantageous for conspicuity), although white buildings reflected less than had been anticipated. The most annoying reflections occurred when the train passed a line of freight cars on an adjacent track; however, the crews reported and demonstrated that these reflections were effectively masked out by turning on the cab lights. It was noted that the headlights on an approaching train at night tended to mask out its strobes at distances greater than one mile — that is, when the visual angle encompassing both headlights and strobes was small. As the train came closer, the strobes appeared to emerge from the headlight glare and become conspicuous. Furthermore, at a distance of several miles at night, a pulsating environment showed the presence of an approaching train long before it became directly visible. Generally, the crews switched on the strobes only when approaching crossings, using the sequence: strobes, bell, and horn. On request, the strobes were left on continuously, but the crews all preferred optional use. Occasionally, the strobes were used as warnings for other purposes, such as on approach to trackside work crews.

3.3 INTERVIEWS

The train crew members operating strobe-equipped trains were recognized as a basic source of information, both on the effects of strobes on their working conditions and on observable effects on the behavior of automobile drivers. Two TSC staff members interviewed crew members about these effects whenever an opportunity arose. The general line of questioning was agreed upon in advance, but the conduct of the interview had to be adapted to the working conditions, generally in the form of conversations with the crew members during lulls in road or yard operations. The wording and sequence of questions were varied to follow up the comments of the interviewees and to compensate for the inevitable interruptions. However, each interview covered the same basic set of questions.

Fourteen crew members were interviewed: two conductors, six engineers, two firemen, and four brakemen. All fourteen interviewees responded "yes" to two key questions: "Does the strobe make locomotives more noticeable at grade-crossings?" and "Do you think the flashing strobe will cut down on the frequency of grade crossing accidents?" Twelve of the interviewees were asked to rate the acceptability of the strobes as a safety device. On a scale ranging from "definitely desirable" to "unacceptable", all twelve selected "definitely desirable."

Eleven crewmen stated that they had detected changes in driver behavior when the strobes were in use; they all noted a tendency for cars and trucks to slow down sooner and to stop farther back from the crossing than had been usual before the strobes were used. Typical comments included: "They should alert a driver unless he's blind or drunk;" "They really alert them (drivers);" "Makes them look;" "They slow down sooner and stop sooner;" "Definitely a plus;" "Definitely will improve safety;" "Didn't see many run across when close."

Regarding interference effects while working with strobes, all fourteen interviewees agreed that the strobes had no effect on climbing in or out of the cab, moving about on walkways, operating controls, reading materials, seeing out of the cab, reading wayside signals, judging speed or distance, or performing other routine tasks. None were blinded by the glare. None felt that the strobes caused them to misread instruments. None saw movements under the lights as jerky. One brakeman complained of mild headache and eye discomfort; none felt nausea. Three brakemen and one conductor felt that the lights might have some effect on working outside the train, especially when reflecting from nearby boxcars. One engineer reported that there were no serious reflection problems in a snowstorm.

Regarding usage, eleven of the fourteen crewmen preferred turning on the strobes only at crossings. One man suggested that public education is desirable: "The driver will see the light, but he may not know what it means." One engineer would like the strobes to be brighter for daytime use. One fireman felt that the strobes are most effective in the daytime, that headlights are just as effective at night.

Miscellaneous comments included the observation that with strobes you acquire a better feeling for the speed of the train, the closing rate of an oncoming train, and especially the position on the track. A conductor commented that there is a greater feeling of security against rear-end collisions when there are strobes up front. An engineer remarked that at night, with all other lights off, the strobes annoy, "... but with one dome light on you don't even notice them."

The interviewers sensed great enthusiasm for the lights among all crewmen. The few annoyances mentioned were considered minor compared to the benefits gained in being able to attract drivers' attention. Typical of the attitude was the plan of the local union president to urge the company and the state DOT to adopt the strobes for regular usage.

3.4 PUBLIC REACTIONS

The evaluation reported here took place during the first few weeks of an extended period of trial usage, and there was not time for the general public to become aware of the experiment and to react. However, the BAR Public Relations Department agreed to act as a collection point for future reactions. Two local trucking companies were visited, briefed on the goals of the project, and urged to solicit observations from their drivers and to forward them to the BAR. A similar arrangement was made with the Maine State Police.

4. EXPERIMENTS

4.1 INTRODUCTION

Although extensive experimentation was not planned for this project, two controlled experiments were included in the total effort. A laboratory study was conducted to study the extent, if any, of the interaction of locomotive-mounted strobe lights with adjacent color light signals, and a field experiment was conducted to sample the behavior of drivers when they unexpectedly saw a strobe-equipped locomotive.

4.2 SIGNAL INTERFERENCE

(1) Purpose. This experiment was run to test the hypothesis that a flashing strobe light in the vicinity of a color signal light will interfere with an observer's perception of the signal's color. Concern had been expressed about the strobe's interaction with track-side traffic control signals, effective use of which requires train crew members to identify the hue of the signal at considerable distances. In the eye of a locomotive crew member observing a distant signal, the image of a strobe on an approaching locomotive on an adjacent track may fall very close to the image of the signal, and the question of the strobe's masking out the color of the signal must be considered.

When flashing incandescent lights had been tested on the rear ends of some trains, crews on following trains had reported interference with signals. The longer flash duration of the incandescent lights served to increase the time of light-adaptation and decrease the recovery time in each cycle as compared to a strobe with a flash duration of well under one-tenth of a second. Nevertheless, further evaluation of the problem was required to be certain that no serious hazard was involved when the strobes were put into road service.

(2) Procedure. A flashing strobe was placed next to a very small signal that could be either red or green, and subjects were asked to name the hue of the signal. The flashing light was a Whelen Strobe, Model 2700. The signal lights were obtained by placing masks containing a hole one-tenth of an inch in diameter over the red and green faces of a highway traffic signal. The immediate background for the signal was a medium gray, with a black background behind it. Viewed from twenty-four feet, each signal subtended the same visual angle as a one-foot signal viewed at 2880 feet. To obtain a "worst-case" situation, the strobe was placed six inches from the signal. Figure 4-1 shows the elements of the stimulus situation. The effective intensity of the strobe was 600 candelas; the intensity of the red signal was 150 candelas, the green 540 candelas.

Ten subjects (TSC staff) were tested, five male and five female. Ages ranged from 17 to 53 years with a mean age of 26 years for females, 36 years for males. Each subject made observations twice with both red and green signals, once in a darkened laboratory and once with overhead fluorescent lighting on. Half the subjects were tested in the dark first, half under the lights first. Each subject, under each condition, was introduced to the viewing position, 24 feet from the stimuli, with the strobe flashing and the signal off. The subject was instructed that a small signal would appear to the right of the strobe and was asked to name the color of the signal. The experimenter then turned on the signal and recorded the subject's response.

(3) Results and Conclusions. All subjects readily identified the red and green signals in the presence of the strobe. No errors were made in identifying the color of the signal and no difficulty in making an identification was reported.

As a result of this experiment, we anticipated no operational problems arising from the interference of the strobe lights with perception of signals in the proposed field tests. We could not predict all conditions that might be encountered in revenue service (such as detection of signals at distances greater than 2880 feet, strobe-signal interaction in fog, etc.), and we recommended that

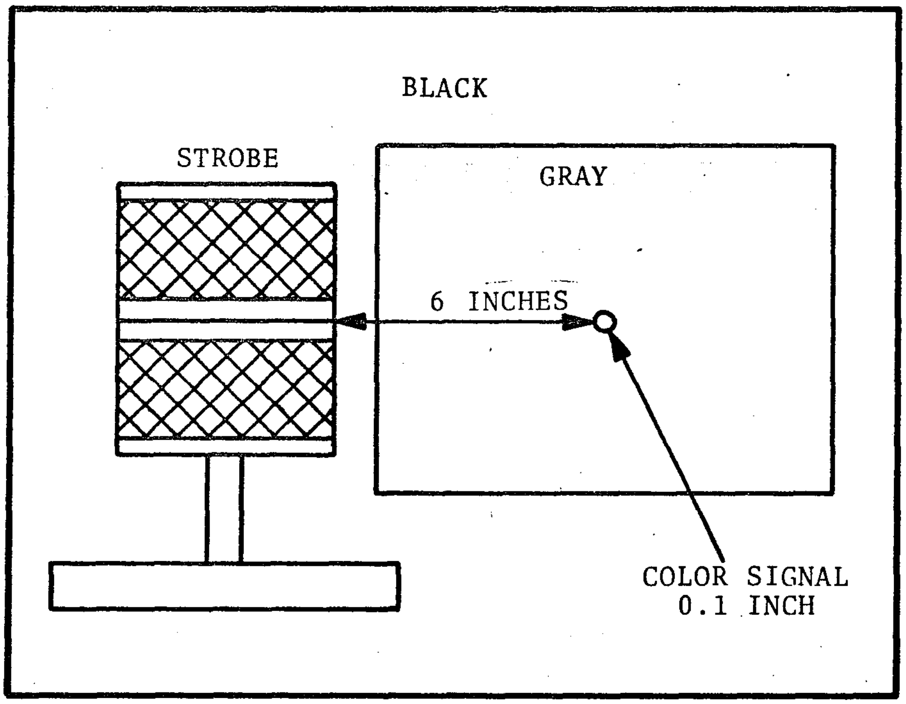


Figure 4-1. Experimental Stimuli

crews be questioned on such interactions as a part of the field study. However, there was no reason to consider strobe-signal interaction as a hazard to safe operations.

In another context, TSC staff members subsequently had the opportunity to observe strobe-equipped trains passing railroad signals. The conclusions from the experiment were substantiated in the field; in no case, day or night, did the strobes affect perception of the signal. It should be noted, however, that when the strobes were viewed three miles down the track, intermediate signals and headlights close to the line of sight masked out the strobes.

4.3 DRIVER REACTIONS

(1) Purpose. This experiment sampled the behavior of drivers approaching a grade crossing who unexpectedly see a nearby locomotive with either headlights or headlights and strobes. It was added to the program of observations as compensation for the fact that all other observers had their attention drawn to the lights before judging their effectiveness, thus possibly predisposing them in favor of the lights and assuring that the lights would be noticed.

(2) General Approach. Subjects were recruited for the stated purpose of driving an automobile in a study of railroad safety. No mention of conspicuity lights was made in the recruiting announcements. Each subject was required to drive an automobile back and forth over a grade crossing, taking "normal precautions." In the course of this exercise, various lights were illuminated on a locomotive standing on the track being crossed, and an experimenter in the car noted the subject's reactions. The experiment was conducted with the cooperation of the University of Maine, using university students as subjects and with Dr. Edward A. Wade of the University's Department of Psychology as experimenter.

In the interests of safety, the experiment was conducted within the confines of the BAR classification yard at Northern

Maine Junction, assuring control of both road and rail traffic at the crossing. Furthermore, the locomotive remained stationary throughout the experiment.

(3) Experimental Conditions. Each subject drove an automobile across two pairs of railroad tracks six times in the following sequence: cross (A), turn around, recross (B), and turn around, repeated three times. Throughout the experiment a locomotive equipped with two roof-mounted strobes and a standard pair of headlights was stationary on one pair of tracks, approximately 400 feet from the crossings. During the first two crossings (1A and 1B), neither the strobes nor headlights were illuminated (control condition). During the second pair of crossings (2A and 2B), either the headlights alone or the headlights and strobes together were illuminated, and during the third pair of crossings (3A and 3B), the alternate light condition was used. Thus, subjects were run in one of two sequences; control - headlights - strobes with headlights (headlights first) or control - strobes with headlights - headlights (strobes first). Strobes were not tested alone, since railroads are required always to light headlights on moving locomotives.

The experiment was run twice on the same day, 16 May 1974. Eleven subjects were run in the daytime (4:15-6:15 pm), and twelve different subjects at night (8:15-11:00 pm). The weather was fair and mild, with increasing high cloudiness during the afternoon becoming a high overcast by sunset. Visibility was unlimited.

(4) Subjects. Twenty-three paid volunteers from the University of Maine served as subjects. The age ranges, gender, and assignment to experimental conditions are summarized in Table 4-1.

TABLE 4-1. ASSIGNMENT OF SUBJECTS TO CONDITIONS

Subjects	Headlights Day	First Night	Strobes Day	First Night	Total	Age Range (Years)
Male	2	3	3	3	11	18-22
Female	3	3	3	3	12	17-22
Total	5	6	6	6	23	

(5) Experimental Site. Figure 4-2 is a sketch of the principal features of the experimental site. The hatched areas are dirt roads and driveways. Subjects approached from the east and entered the test area by making a right turn around the corner of a utility building. They drove across the first two tracks, turned around, recrossed the tracks, turned around at the building, and repeated. In the daytime, the locomotive was visible on the approach (as was other railroad equipment in the yards) but near the building it was masked from sight by bushes. Experimental locomotive lighting conditions were always changed while the subject was turning around at the building. The appearance of the locomotive as a driver approached the crossings in direction A (first view of each lighting condition) is shown in Figure 4-3. Figure 4-4 shows a subject recrossing the track (direction B) with the locomotive in the background.

(6) Procedure. The same procedure was used for the day and night experiments. In each case, all subjects were assembled in a building about half a mile from the test site. Welcoming remarks were made, and general instructions regarding safe behavior on railroad property were given. Subjects were run individually, all waiting their turn in the assembly building.

A subject and the experimenter entered the automobile, a recent model four-door sedan, with the subject as driver. Seat belts were fastened, and general instructions for handling the car were given. The following instructions were then read to each subject:

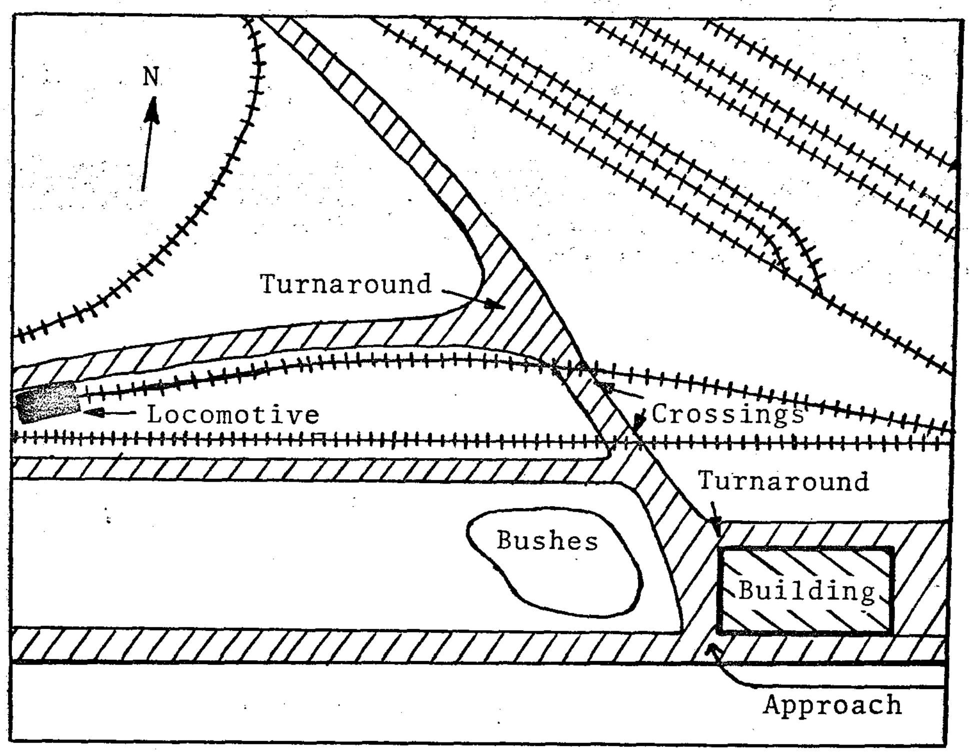


Figure 4-2. Principal Features of the Experimental Site

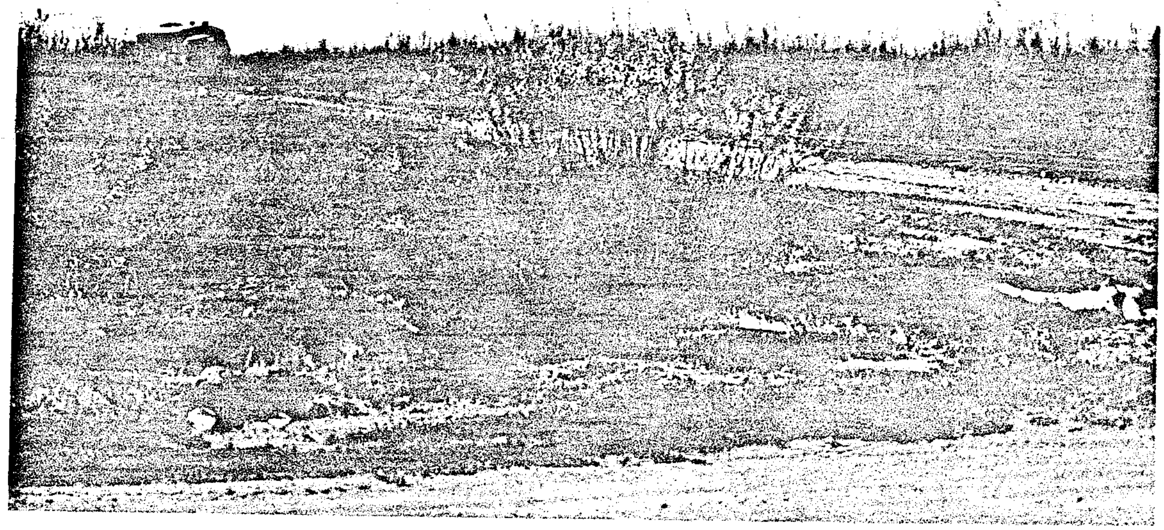


Figure 4-3. Appearance of the Locomotive on Approaching the Crossings, Direction A.

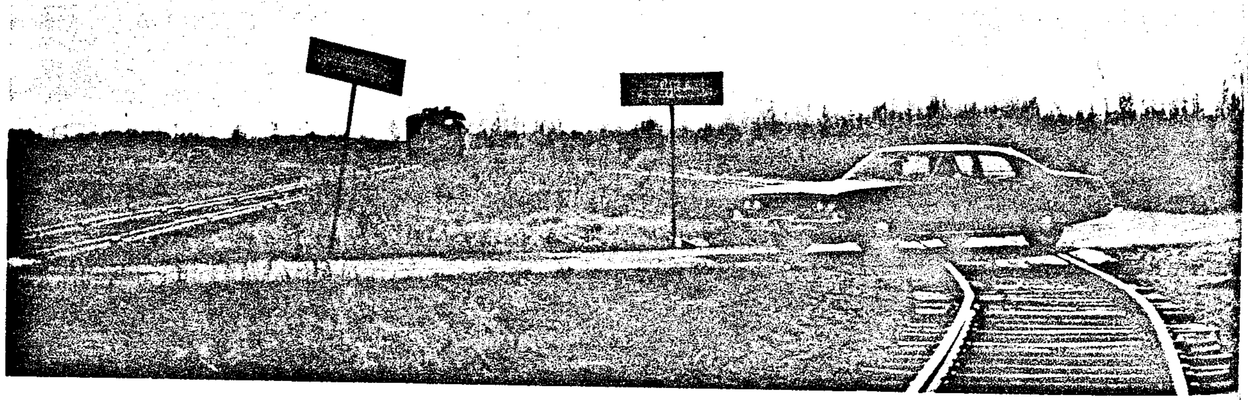


Figure 4-4. Subject Driving Vehicle at Crossing, Direction B

"The purpose of this study is to examine factors related to railroad safety. We are interested in driver behavior in and around grade crossings. Your job will be to drive the automobile along a road parallel to the railroad and then across some sets of tracks. The tracks <u>may</u> bear traffic, so observe normal precautions. The grade crossing is a short driving distance from here. There is a small building near the crossing that serves as a watchman and control point during working hours in the rail yards and we may see some railroad personnel there. After your task is over we will be asking you to wait at that point while other subjects are run. We will cover the route three times. The first time along the route will be to familiarize you with the road, the location of the crossing and some places where we will be reversing direction. On subsequent trips, we will have you cross the tracks so that we can get your reaction to the handling characteristics of the car. We will be interested in your impressions."

"Are there any questions before we start?"

When the experimenter judged that the subject was ready, they drove to the experimental site and executed the six crossings as planned. The subject was then taken to the site building to answer detailed questions concerning observations and reactions to the experiment. The experimenter returned to the assembly building for the next subject. To avoid inadvertent disclosure of the purpose of the experiment, subjects remained at the site building until all had participated.

(7) <u>Results</u>. There were four sets of results to consider: observations of subjects' behavior by the experimenter during the crossings, spontaneous comments of the subjects during the crossings, answers to questions following testing, and spontaneous comments after testing.

(8) <u>Observations of Cautious Behavior</u>. The experimenter made notes of the subjects' behavior and comments as they occurred in the car. The observed behavior was subsequently

classified into six categories of cautious behavior: slowed down at crossing; stopped at crossing; stopped between crossing; looked around on approaching crossing; and looked back at the locomotive. No consistent differences due to gender were noted in cautious behavior; so male and female data have been combined for analysis. Table 4-2 summarizes for each condition the number of observed instances of each type of cautious behavior. The number of observations within individual categories of behavior are too few to warrant analysis. The gross totals fail to show any significant differences between the number of observed instances of cautious behavior when the headlights were showing (81) and the number when strobes were flashed with the headlights on (83), nor do the day-night breakdowns reveal anything significant in the totals.

There are some suggestive patterns of behavior, however. First, regardless of conditions, sequences of observations have been plotted for both day and night conditions in Figure 4-5, revealing a consistent pattern in the daytime data. The frequencies for direction A, when the car first crossed the tracks under any condition, are greater than the frequencies for direction B, the return crossing under each condition. The total frequencies for direction A are significantly greater than the frequencies for direction B ($p<.01$)* in the daytime data, giving a picture of less caution, or more confidence on each return run in the daytime. There is a consistent, though not significant, tendency for less caution in the third run in each direction. There is evidence of immediate habituation to each situation, but with an increase of caution for each change in conditions. At night, however, caution is maintained at the initial level (frequencies for both directions not significantly different) once either lighting condition is in effect, although the initial control condition (crossings 1A and 1B) shows behavior similar to the daytime.

*The chi-square test of significance was used to compare frequencies. The p value shows the probability that the observed frequencies would have been observed if they were only chance departures from the same true frequency. Values of p of .05 or less are accepted as statistically significant.

TABLE 4-2. NUMBER OF CAUTIOUS ACTIVITIES OBSERVED

		SEQUENCE												TOTALS					
		Headlight First						Strobe First						Head-light			Strobe		
		1A	1B	2A	2B	3A	3B	1A	1B	2A	2B	3A	3B	A	B	Σ	A	B	Σ
	Day	4	2	3	2	2	1	4	2	5	1	4	2	7	4	11	7	2	9
	Night	3	4	4	3	4	1	5	1	1	2	5	3	9	6	15	5	3	8
Slow down at X-ing?	Total	7	6	7	5	6	2	9	3	6	3	9	5	16	10	26	12	5	17
	Day	2	0	3	0	2	0	2	0	0	0	3	0	6	0	6	2	0	2
	Night	3	0	4	2	4	2	1	0	4	4	1	0	5	2	7	8	6	14
Stop at X-ing?	Total	5	0	7	2	6	2	3	0	4	4	4	0	11	2	13	10	6	16
	Day	0	0	0	0	0	1	0	0	0	2	0	1	0	1	1	0	3	3
Stop between the two tracks?	Night	0	0	0	2	2	2	0	0	1	1	1	2	1	4	5	3	3	6
	Total	0	0	0	2	2	3	0	0	1	3	1	3	1	5	6	3	6	9
	Day	5	4	3	1	3	0	5	2	5	1	5	1	8	2	10	8	1	9
	Night	4	1	3	1	5	0	4	2	3	2	5	0	8	1	9	8	2	10
Look around?	Total	9	5	6	2	8	0	9	4	8	3	10	1	16	3	19	16	3	19
	Day	0	0	1	1	0	0	1	3	3	5	0	4	1	5	6	3	5	8
Look back at locomotive?	Night	0	4	1	4	3	6	0	1	3	2	1	5	2	9	11	6	8	14
	Total	0	4	2	5	3	6	1	4	6	7	1	9	3	14	17	9	13	22
	Day	11	6	10	4	7	2	12	7	13	9	12	8	22	12	34	20	11	31
	Night	10	9	12	12	18	11	10	4	12	11	13	10	25	22	47	30	22	52
Totals	Total	21	15	22	16	25	13	22	11	25	20	25	18	47	34	81	50	33	83

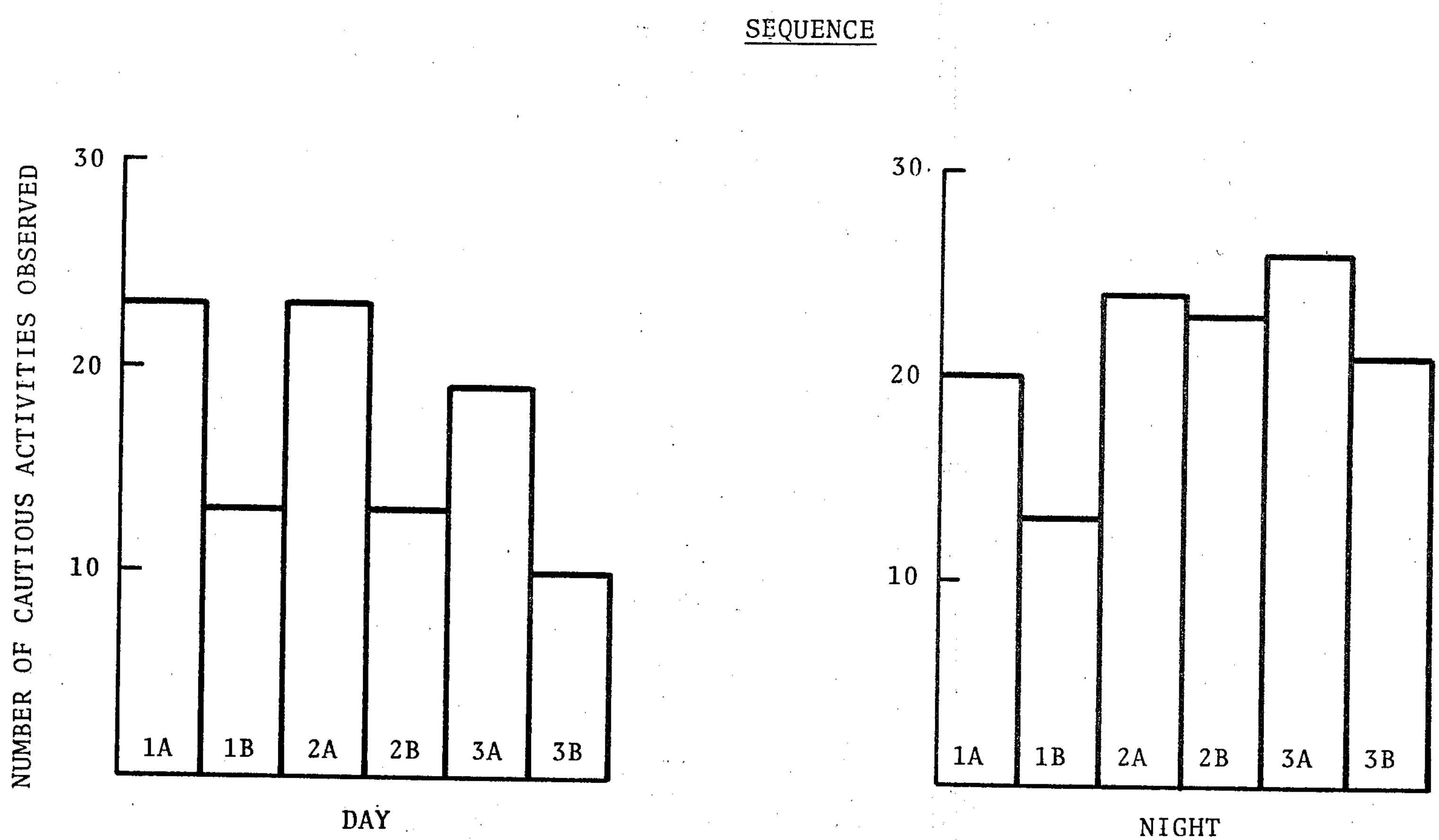


Figure 4-5. Number of Cautious Activities Observed by Sequence

Thus, there is evidence of the effectiveness of the lights (either type) in preventing loss of caution.

In Figure 4-6, the same data are broken down to show the differences between subjects observing headlights first and those observing strobes first. The behavior pattern for subjects seeing headlights first in the daytime is the same as for the total group -- caution decreasing on return runs, renewed on approaches after changes in lighting. The frequency differences between crossings in the A and B directions are again statistically significant ($p<.01$). However, the decrease in cautious behavior for those subjects seeing the strobes first in the daytime is much less marked and does not bear statistical significance. At night, both groups maintained alertness after the control runs, the headlight-first group showing extra caution when subsequently seeing the strobes.

Since the day and night data were taken on different subject groups, the observed differences could reflect general differences in driving behavior in the two samples. However, all subjects were volunteers from the same population; no bias was exercised in their assignment to day and night conditions; both groups showed similar behavior on the control runs; and the behavior differences are consistent with the observed conspicuity of lights at night and with subjects' comments.

We conclude from observed cautious behavior, that either the headlights or the strobes caused some increase in cautious behavior, which tapered off rapidly in the daytime when the initial warning was headlights only but was maintained when strobes were seen first. At night, a relatively steady level of cautious behavior was maintained, with the highest jumps in cautious behavior occurring on first sighting the strobes (frequencies not statistically significant).

(9) Comments in Car. The experimenter made notes of the spontaneous comments of the subjects as they drove back and forth over the tracks. Only two comments were made during the day runs, both by strobe-first subjects on seeing the strobes for the first

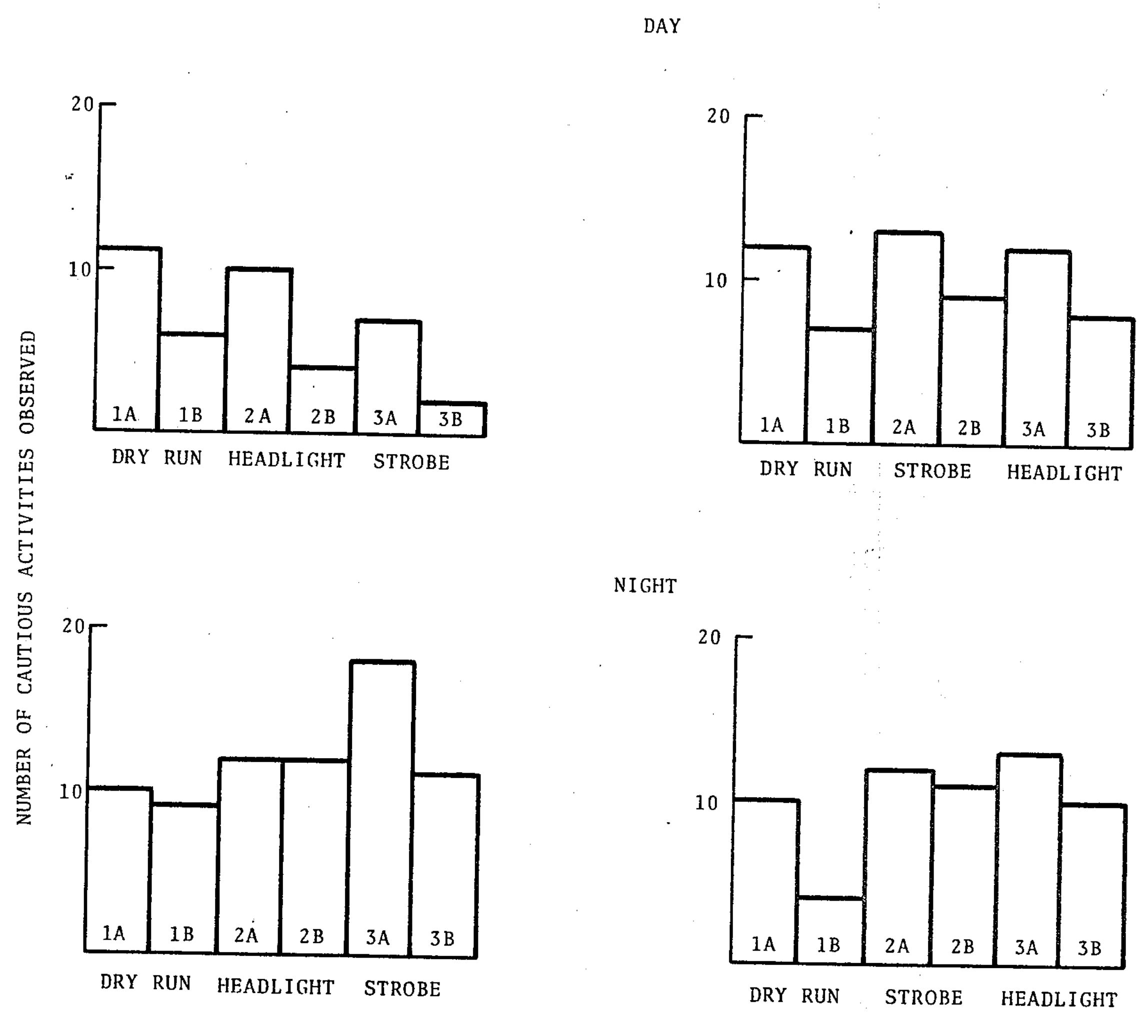


Figure 4-6. Number of Cautious Activities Observed by Experimental Conditions

time. One remarked: "I keep thinking it's going to do something," the other: "What's the train doing with the lights flashing?"

At night, thirteen comments were noted. Five expressed uncertainty as to whether the locomotive was moving, four on seeing headlights, one on seeing the strobes. Two subjects each commented on uncertainty as to where the locomotive was, on whether they should stop, and on general distraction, five of the six comments being stimulated by the headlights. One subject double-checked the location of the locomotive ("I guess he's not moving."), and one was uncertain as to what the headlight signified.

(10) Answers to Specific Questions. Each subject was asked several specific questions immediately following the run. Table 4-3 summarizes the responses to some of these questions and shows where frequencies of answers differed significantly. The strobes clearly gave the impression that the locomotive was moving at night, with impressions evenly split for all lights in the daytime and headlights at night. Most of the subjects felt that the strobes make a train more conspicuous at night and should be on all locomotives, but should be turned on only at crossings. In the daytime, very little interference with vision, judgment and general well-being was experienced due to flashing lights; a few subjects reported interference with vision (5) and judgment (3) at night, but only one reported feeling dizzy or upset. All subjects had noticed the locomotive during the control runs (1A and 1B).

Another question called for recall of general reactions on first seeing the headlights and the strobes. Nine responses involved uncertainty as to whether the locomotive was moving in the daytime, four for headlights and five for strobes, while at night there were fourteen cases, five for headlights, nine for strobes. Seven subjects said they double-checked the locomotive before proceeding, three in the daytime, four at night, about evenly divided between headlights and strobes. Seven subjects considered stopping, two in the daytime, five at night, again about evenly divided between strobe and headlight. Four

TABLE 4-3. ANSWERS TO SPECIFIC QUESTIONS

	Day		Night	
	Yes	No	Yes	No
1. Did you get the impression that the locomotive was moving				
a) when the flashing lights were on?....	4	6	10 *	2
b) when only the headlight was on?......	5	5	5	7
2. Do you think that the flashing light makes a locomotive more noticeable at grade crossings?......................	8	2	11 *	1
3. Do you think that the flashing light should be left on all of the time?......	0 *	10	6	6
4. Or do you think that the light should just be turned on when the train is approaching grade crossings?...........	10 *	0	6	5
5. Do you think that flashing lights should be installed on all locomotives?........	10 *	0	10 *	2
6. Did flashing light ever				
a) interfere with your vision..........	0 *	10	5	7
b) affect judgment of speed or distance to the crossing.....................	1 *	9	3	9
c) make you feel dizzy or upset.........	0 *	10	1 *	11
7. Was a locomotive present when you first crossed the tracks to get a feel for the road, etc.?..........................	11 *	0	12 *	0

*Significant at the .05 level

additional subjects considered slowing down at night. Three reported uncertainty about the locomotive's location or speed at night.

Another question asked whether the locomotive appeared closer with the headlights or the strobes. The daytime subjects showed no clearcut opinion, but ten of the twelve night subjects thought the locomotive looked closer with the strobes.

A question asking subjects to recall whether they saw strobes first or headlights first produced curious results. Two of the day subjects and four of the night subjects who had seen strobes first recalled seeing the strobes last, while all of the headlights-first subjects recalled the sequence of conditions correctly. Apparently the strobes made a strong impression on the memory of subjects.

(11) Spontaneous Comments. Nine additional spontaneous comments were recorded during the post-test questioning, but they simply added one each to categories already identified.

(12) Discussion. Several factors related to safety precautions militated against getting more clearcut results in the experiment. The controls (hired subjects, in-yard location, experimenter in car) made the subjects "test-conscious" — they were alert, expecting something to happen. On the other hand, these same precautions plus the fact that the locomotive was stationary probably made them less cautious at crossings — the feeling that experimenters would not let them be exposed to real danger. This is borne out by the rapid decline in cautious behavior on recrossings. Another significant factor was forced by the general terrain. On each initial turnaround, the subject looked directly at the front of the locomotive, and on the second and third runs, he looked directly into the headlight beam, a condition that would not occur normally at a crossing and one that certainly left the subject with a strong impression of the headlight.

Within the limits of these conditions, we get a general feeling of subjects' concern, both from behavioral observations and comments of the subjects. The principal item of concern seems to be a questioning of what is happening — often in the form of: "Is that train moving, or getting ready to move?" This concern was sparked both by the headlights and the strobes, with perhaps a small tendency for the strobes to cause greater concern at night. In the daytime, cautious behavior declined after the initial reactions to the headlights, but was maintained in the daytime when strobes were used first and was maintained, and perhaps increased, for both headlights and strobes at night. Following the experiment, the majority of these subjects indicated that they thought strobes would make trains more conspicuous at crossings and that they should be installed on all trains.

ground close to the strobes. There was little information available on the effects of long-term backscatter from fog or falling snow, but on the few occasions that had occurred crewmen noted no problems. Crewmen stationed at the rear of the train had noted trouble in inspecting their train while looking toward the strobes, suggesting the desirability of masking off the beam directly to the rear. Because of these annoyances, which might be aggravated with prolonged exposure, it is desirable to give the engineer the option of turning off the strobes when he feels they are not needed. Even the crewmen who noted these side effects generally considered the use of the strobes at grade crossings highly desirable. Observations and an experiment failed to show any strobe interference with immediate accurate perception of trackside color signals.

5.2 RECOMMENDATIONS*

(1) The Use of Flash Tubes Giving a High-Intensity Flash of Short Duration Should be Considered as a Means of Increasing Locomotive Conspicuity. Xenon strobes flashed at 1-2 Hz were shown to be effective and relatively problem free. This is not to say that other types of lights, meeting the basic requirements shown in Table 2-1, would not be equally effective.

(2) The Operation of Flashing Strobes on Locomotives Should be Under the Control of the Engineer. Although our study uncovered no serious side effects, there is the possibility that prolonged exposure to flashing strobes at night, particularly where there is considerable backscatter into the cab, might be undesirable. Crews were given the choice of continuous operation or operation only when desired, and all consistently chose optional operation. From an operational point of view, this procedure is no different than the selective operation of the horn and bell and can be controlled similarly through appropriate operating rules.

*More detailed recommendations on selection and use of strobes to enhance locomotive conspicuity will be found in John B. Hopkins and A. T. Newfell, "Guidelines for Enhancement of Visual Conspicuity of Trains at Grade Crossings," FRA-OR&D-75-71, May 1975.

(3) The Strobes Should be Operated at 800 Candelas Effective Intensity at Night, 4000 Candelas in the Daytime. Several observers and interviewees suggested that a higher level of intensity might be desirable in the daytime, and the results of the field experiment were more ambiguous for the daylight condition. Observations made by one of the authors for a different purpose showed that a 4000-candela light had better visibility and no adverse side effects in the daytime. To avoid inadvertent use of the high-intensity setting at night, the setting should be controlled by a photo-cell that senses ambient illumination.

(4) The Rear Thirty Degrees of the Strobe Beam Should be Masked Out. This precaution permits crew members to make visual checks of the front end of the train from behind without looking directly into the strobe's beam.

(5) Additional Studies Should be Conducted. Several operating conditions were not checked in the BAR studies. Prolonged operation of the strobes in dense fog and in heavy snowstorms should be evaluated to obtain more information on backscatter effects and crew tolerance. The effects of the 800-candela strobe on nearby motorists should be checked under the darkest ambient conditions possible (unlighted highway on an overcast, moonless night). Alternative lighting systems should be evaluated comparatively. The Crane Study (Sanders et al., 1974) failed to show any marked differences among several alternative conspicuity light systems, although xenon strobes were preferred by most of the subjects. The possibility that systems equal or superior to xenon strobes are available should not be overlooked.

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