TOWARD MORE EFFECTIVE GRADE-CROSSING FLASHING LIGHTS

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Pairs of alternately flashing, red incandescent lamps have been the primary motorist warning device at grade crossings for several decades. Although significant evolutionary improvements have occurred, basic constraints (on power consumption, in particular) have limited the total effectiveness normally found. Tightly focused beams, which are necessary to obtain high intensity at low power levels, make perceived brightness highly dependent on both motorist position and precise alignment, which is difficult and expensive to maintain. Examination of appropriate literature and existing standards has made possible delineation of functional specifications and desirable characteristics of motorist warnings for use at grade crossings. Significant improvement is possible through the use of xenon flash lamps in standard crossing mountings, in place of or in concert with conventional lights. The short-duration flash of the xenon unit appears to offer a warning of markedly greater effectiveness. This result is obtainable with little deviation from the basic framework of applicable standards, motorist familiarity, and conventional equipment. This paper includes discussion of optimal specifications, relevant technology, compatibility with existing systems, and field tests.

•THE BASIC train-activated flashing lights now found at many railroad-highway grade crossings, either alone or in conjunction with automatic gates, have been in use for more than 50 years. Although many improvements have occurred in both performance and construction, the aspect presented to the motorist has become well standardized. The lights consist of 2 incandescent lamps mounted in reflectors behind red lenses. The lamps are aligned horizontally at a spacing of 30 in. (76.2 cm) against a 20-in. (50.8-cm) circular black background and are flashed alternately at a rate of 35 to 55 flashes/min for each lamp (Figure 1). Indeed, the history of this basic pattern can be traced back through the electromechanical wigwag signal to the motion of a man swinging a red lantern (1).

Such warnings generally have been found to reduce the occurrence of grade-crossing accidents by 60 to 80 percent (2). They are found at an estimated 41,600 of the 223,300 public crossings in the United States; they are accompanied by automatic gates in approximately 9,000 cases (3, 4). Through the years, the railroad supply industry has advanced the technology of these lights substantially, particularly in recent times. In addition to improved mountings and reflectors, lenses incorporating more efficient beam patterns and fabricated from nearly unbreakable polycarbonate materials have been developed. Higher intensity bulbs are now offered, and special reflectorization is available. Quartz-halogen lamps are now on the market along with 12-in. (30.5-cm) assemblies [the standard size is $8\frac{3}{8}$ in. (21.3 cm)].

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These changes generally have contributed to greater brightness and improved beam patterns. However, all the changes have occurred within a framework that has severely limited major innovation. It is the purpose of this paper to review the nature and consequences of these constraints and the function of grade-crossing warnings and to describe application of alternative lighting technology. Analytical and experimental investigations along with preliminary field-test results will be reported.

BACKGROUND

Perhaps the most fundamental limitation on conventional warnings is the very low power consumption permitted. It is generally considered necessary (and legally required) that grade-crossing protective systems be able to operate from batteries for periods of 1 to 7 days in the event of any failure of commercial power or power-system components (such as fuses). This constraint coupled with the large number of lights commonly used at a crossing (typically 4 pairs and sometimes 3 or 4 times that number) led to use of 11-W bulbs for many years; 18-W bulbs now are standard, and 25-W bulbs are coming into wide use. When these figures are compared to the 60- and 150-W ratings of bulbs used in highway traffic signals, it becomes obvious that adequate intensity can be obtained only by tightly focusing the lights to a narrow beam. This is the course that has been followed; a special roundel design provides a diversion of a limited quantity of light in certain directions to include motorists not located within the main beam. This limitation has been exacerbated by the use of a very deep shade of red, which attenuates light output by approximately 90 percent. However, the modern use of plastic lenses now permits use of a substantially lighter shade of red. It also permits much tighter manufacturing tolerances than are possible with glass; therefore, roundels can be produced at the lighter limit of existing standards. Because of the technical constraint, serious limitations arise in terms of their effectiveness as a motorist warning device.

The challenge is to provide an adequately intense light to all positions that a motorist might occupy. Even use of 2 or 3 pairs of lamps aimed to provide overlapping coverage of the entire approach path often appears to be only marginally adequate. Further, a driver might easily focus his or her attention on a pair of lights other than that appropriate to his or her position and, as a result, might be warned inadequately. This difficulty has tended to increase in recent years because lights have been located farther from the road, both vertically (with cantilevers) and horizontally (beyond highway shoulders). This difficulty is a primary cause of the common (but incorrect) impression that grade-crossing lights are inherently less bright than conventional highway traffic signals.

Of comparable importance in practice is the great sensitivity of such a device to misalignment. Whether through misplacement of the bulb, faulty aiming of the assembly, use of an inappropriate roundel, or physical movement because of accident or malicious vandalism, very little deviation is required to degrade seriously the effectiveness of the warning. The railroad environment makes difficult the attainment and maintenance of optimal conditions. Extremes of weather, continual vibration, and sabotage make probable the fact that the lights will deviate somewhat from proper aim at any given time.

Another apparent shortcoming of conventional lights relates to the function they serve. The signals at highway intersections generally are referred to as traffic control devices. It is reasonable to assume that motorists generally perceive that an intersection is ahead, that a hazard exists, and that it is prudent to determine whether either active or passive traffic control devices are present. Active warnings generally proclaim their presence by a flashing or continuous light. None of these factors can be assumed at a grade crossing. The presence of a railroad-highway intersection may not be noted until it is quite close, and the situation may be understood poorly. Indeed, a recent study shows that many motorists have a highly imperfect knowledge concerning grade crossings and sometimes make unwarranted and dangerous assumptions (5). Thus the function of active warnings in this application goes well beyond the normal, informative, traffic control purpose and must include alerting the motorist to a potentially hazardous situation that requires careful attention. In other words, for grade-crossing flashing lights merely to inform vehicle operators that a train is present (or soon will be) is not sufficient; they also must ensure, insofar as possible, that they are first seen. National Highway Traffic Safety Administration multidisciplinary accident investigation reports suggest that collisions often are associated with warnings that were present and operating correctly but that were not perceived.

IMPROVEMENT CRITERIA AND OBJECTIVES

The previous discussion is intended to suggest aspects of conventional grade-crossing flashing lights that warrant efforts at improvement. It is appropriate to establish necessary and desirable quantitative performance specifications. However, if this is to be more than an academic exercise, technical objectives must be determined within a realistic framework.

Compatibility with Existing Practices

Conventional protection is well defined by Cox (6) and by the Association of American Railroads (AAR) (7, 8, 9). If one were to attempt to work entirely within these specifications, little improvement would be possible because they are a codification of existing technology and practices. However, acceptance of the major part of these standards raises no problems. The use of alternately flashing, horizontally aligned red lights is common primarily to crossings and enjoys widespread motorist recognition. Thus details of component dimensions and location can be accommodated readily in developing an alternative system.

Retaining current motorist recognition and compatibility with existing engineering and construction practices is highly important. Recent analysis indicates that the number of crossings likely to warrant new installation of active protection is substantially smaller than the number that already have it (and approximately 40 percent of deaths now occur at protected crossings) (3, 4). Thus the potential benefits of improved devices will be limited sharply unless upgrading and retrofitting are relatively simple and inexpensive.

That grade crossing warnings be as close as possible to all other motorist warning and traffic control devices is important. Thus the Institute of Traffic Engineers standards for traffic signals (10) can provide useful guidelines on color, beam width, and intensity. In more general terms, the Manual on Uniform Traffic Control Devices (11) includes a substantial body of information on location and use of traffic controls.

Functional Requirements

The fundamental quantitative specification needed for warning lights is intensity. This is not a simple matter. The brightness required for "adequate" warning depends on an individual's physical and emotional characteristics, ambient light level, and the entire visual context. This problem has been treated by others, and the results of a study by Cole and Brown (12) on traffic signals have been adapted for use in this paper. Cole and Brown's basic finding is that the source intensity I_o (in candelas) appropriate to a viewing distance d [in feet (meters)] with a certain ambient luminance L_b [in foot-lamberts (candelas/meter^2)] is given by the expression

$$I_o = 6.37(L_b + 2.92)d^2 \times 10^{-7}$$

For example, the expression, "normal daytime conditions," [L_b = 2,919 ft-L (10 000 cd/m^2)] implies that a value of 200 cd for I_o is necessary for a viewing distance of 330 ft (100 m). Background luminance at times can reach 3 to 4 times this value. The intensity required to alert as well as inform can further increase this value. However, this equation provides a useful starting point and can be modified readily if necessary. [Under night conditions, it is important that intensity not be so great that motorists are bothered or hampered in their actions. Tests in a different but related research activity indicate that a level of 200 to 500 cd is likely to be acceptable for an observer 20 to 50 ft (6 to 15 m) from the lights (13).]

The perceived brightness at the eye of the motorist depends on the lamp, intensity, and beam shape; the location and aim of the light; and the observation distance. The illumination pattern must be such that, as a motorist approaches the signal and typically moves out of the brighter central part of the light beam, the resultant decrease in brightness will be compensated for by the reduction in viewing distance so that Cole and Brown's criterion can continue to be met. This must be true for a variety of possible light locations and viewing points. It would be highly impractical to require a large number of roundels or optical systems for different cases or to expect that the correct ones always would be used. In addition, substantial margin is required to allow for some degree of misalignment and the likelihood of curving or undulating approach roads.

There are 2 basic situations to be covered: roadside installation and cantilever mounting above the traffic lanes. For roadside installation, both driving lane and shoulder may be wide or narrow so that the light may be displaced horizontally from the vehicle path by an amount that could range easily from 10 to 35 ft (3 to 11 m). Vertical spread is of less concern because the common mounting height is approximately 8 ft (2.4 m), but the mounting height must accommodate vehicles from sports cars [driver eye height = 40 in. (101.6 cm)] to large trucks [driver eye height > 100 in. (254 cm)]. Grades on the approach road, particularly when they are undulating rather than constant, can have a marked detrimental effect. For cantilever-mounted lights, vertical spread can be a severe problem. With a typical mounting height of 18 ft (5.5 m), the angle at which a driver views the lights can change substantially as he or she approaches, especially if grades are involved. This difficulty normally is alleviated by use of additional short-range lights, but the subject of this study is systems that, like traffic lights, require no such compensation.

Experience in a variety of similar applications (marine, aviation, and highway) and recent research concerning railroad applications indicate that the combined flash rate (with alternate flashing) should be at least 90/min (1.5 Hz), and a rate of 120/min (2 Hz) is preferred. Practical considerations militate against values higher than 3 to 4 Hz, and rates between 6 and 12 Hz can have seriously disturbing effects on some individuals and should be avoided.

A given amount of radiant energy can be used as a short, high-intensity flash or a longer pulse at reduced intensity. This suggests the desirability of using very short, very intense pulses in cases for which power efficiency is important. However, the perceived brightness of flashes that are markedly shorter than the response time of the eye (~0.1 s) is basically determined by total flash energy alone; therefore, no further benefits are obtained for shorter flashes. Numerous studies of this complex topic confirm that the power efficiency with which a given perceived brightness level can be obtained increases as duration decreases to approximately 0.1 s; little improvement is found below that interval.

Little elaboration need be given to the obvious practical requirements, such as installation costs and power consumption comparable to or less than current systems, minimal maintenance needs, and commercial availability without extensive development.

REALIZATION OF AN IMPROVED SYSTEM

Introduction

The key to making a meaningful system improvement is shortening flash duration. Cycling an incandescent bulb at the pulse durations desired is not practical because of filament heating and cooling times; therefore, an alternative is needed. Electromechanical devices, such as rotating beacons, can provide the desired effect. However, considerations of cost, complexity, and maintenance requirements as well as synchronization and easy adaptation to existing systems combine to make this an unpromising approach.

On the other hand, short-pulse beacon applications in space, marine, aviation, highway and, more recently, railroad rolling stock have made increasing use of xenon flashtube (capacitive discharge) lamps (14, 15). In such lights, the energy stored in a capacitor ($0.5\ cV^2$) is released (primarily as visible radiation) by electrical discharge across a xenon-filled gap. The process is initiated by an applied trigger signal so that precise timing and synchronization are possible; duration is typically less than 0.001 s. Application of this technology to grade crossings was examined in the mid-1960s by Scott and Moe of Safetran Systems Corporation. Their field installations used a burst of xenon flashes in place of each conventional flash. However, the multiplicity of flashes and limitation to dark red lenses made it impossible to obtain satisfactory intensity within the power consumption then considered permissible. The Union Pacific Railroad in recent years has installed xenon lights in addition to conventional flashers in a variety of forms at many operating grade crossings; generally, it has met with good results. This work and the fact that lighter reds and incandescent lights of higher power consumption have come into use indicate the feasibility of xenon lights. A detailed report on comprehensive research into the technical foundation for design and characterization of xenon grade-crossing flashing lights is available elsewhere (16).

The Effective Intensity Concept

Because of the relationship between flash duration and alerting effectiveness and the typical variation of light intensity during the pulse, short-flash lights generally are characterized in terms of effective intensity, which is a measure of the steady intensity necessary for equivalent conspicousness of a point source for brightness near the threshold of detectability. Mathematically, this may be calculated from the Blondel-Rey equation

$$I_e = \frac{1}{0.2 + (t_2 - t_1)} \int_{t_1}^{t_2} I(t)dt$$

where

I_e = effective intensity in candelas,
$I(t)$ = instantaneous intensity,
t_1 = beginning time of flash, and
t_2 = end time of flash.

The term intensity, when used in connection with xenon flash lamps, means effective intensity.

Color

The general connotation of red for traffic signals and the long history of use of that color in grade-crossing protection are compelling reasons for retaining its use. However, the term red is by no means precise. (Colors are often conveniently specified in terms of chromaticity coordinates, which provide a unique characterization for every combination of hue, brightness, and saturation.) The color of light emitted from a lamp depends on both the source and the lens. Radiant energy from a xenon discharge has an effective color temperature of more than 6000 K compared with 2800 K for typical incandescent lamps. In other words, much of the light output is in the blue end of the spectrum. This makes particularly important the use of a red roundel that is sufficiently "light" (approaching orange-red instead of the deeper shades).

It has been commonly thought that AAR specifications require use of dark red, which attenuates light by more than 90 percent. In fact, this is not the case. The specifications for highway crossing red permit relatively light shades that are comparable to those allowed by the Institute of Traffic Engineers and the Society of Automotive Engineers. Traditionally, a relatively dark color has been used partly because of the large manufacturing tolerances required for glass lenses. Now that plastic roundels have come into widespread use, several manufacturers are producing light red lenses that fall within AAR standards but offer much greater transmission. This lighter color is particularly beneficial for xenon lamps with their high color temperature and limited output in the red portion of the spectrum. It is also desirable for the approximately 2 percent of the population with red-color-deficient vision.

It should be noted that one can afford considerable latitude in color selection without seriously degrading motorist response. For most traffic signals as well as for railroad block signals, discrimination between red and amber is crucial. However, at grade crossings only the 1 color is present; therefore, the overall context makes misunderstanding unlikely even if a red-orange hue is used.

Experimental Units

Modification of conventional grade-crossing flashing-light assemblies has been found to be relatively simple. A xenon flashtube and socket are installed easily in place of the incandescent components. The xenon discharge takes place over a volume that is large compared with that occupied by a filament; therefore, the sharp focusing conventionally found is not observed. As a result, normal roundels (designed to defocus a narrow beam in a controlled and desirable manner) have only a small effect on the consequent pattern, which has a substantially wider beam width than that of the incandescent lamp. Xenon lamps are available mounted in standard 8-in. (20.3-cm) sealed-beam housings. These are attractive not only because of the simplicity of their use but also because a further improvement in pattern is obtained. Figure 2 shows the measured pattern in the vertical plane for a 12-in. (30.5-cm) "narrow-beam" traffic signal and for a standard mounting and long-range roundel that uses an 18-W incandescent bulb and a sealed-beam xenon flashtube.

Theoretical Performance

To estimate the effect of the altered pattern on a motorist, we made calculations of received illumination as a function of observer distance from the crossing for a variety of lamp characteristics and flashing light locations. Figure 3 shows some of the calculations. Line 1 is for a conventional light with a "long-range" roundel; line 2 is for a conventional light with a standard roundel; line 3 is for a 12-in. (30.5-cm) narrow-beam traffic light; and line 4 is for a xenon light in a standard grade-crossing mounting. Intensity normalized to Cole and Brown's criterion is shown as a function of distance from the crossing. A background luminance of 30 000 cd/m^2 was assumed, which is equivalent to a very bright day; a value of unity in Figure 3 meets Cole and Brown's definition of adequate intensity. (Alternatively, one could interpret these curves as descriptive of normal brightness with a criterion that crossing protection warnings should have 3 times the intensity of normal traffic control devices.) The calculations in Figure 3 are for a lamp located at the edge of an 11-ft (3.3-m) shoulder; similar results are obtained for cantilever-mounted lights. The basic result is clear. Narrow-beam lights can provide good coverage at a distance, but as soon as one drives out of the beam, the intensity drops sharply. Wider beams generally sacrifice peak intensity, but the vehicle stays within them as the distance decreases so that the square-law increase in received illumination strongly dominates the beam pattern effect until one is very near the crossing. (In practice, the near region is covered by use of a second pair of lights.) The sensitivity of the narrow-beam systems to proper aiming is shown in Figure 4. Again, line 1 is for a conventional light with a "long-range" roundel; line 2 is for a conventional light with a standard roundel; line 3 is for a 12-in. (30.5-cm) narrow-beam traffic light; and line 4 is for a xenon light in a standard grade-crossing mounting. The effect on the conventional crossing light is extreme; road undulations and curvature have similar effects.

Power Consumption

As we have noted, restrictions on power consumption are a major constraint on conventional systems and are, in fact, the reason for use of narrow-beam lights. Thus this characteristic is crucial to the workability of any proposed alternative. Although much of the energy radiated by a xenon lamp is in the infrared and ultraviolet range, approximately 50 percent remains in the visible portion of the spectrum. Conversion of electrical energy into light is normally at an efficiency of 5 to 10 percent; therefore, conversion into visible light is at 2.5 to 5 percent efficiency. The net result is that one normally can expect approximately 30 lm/W of input power. The equivalent figure for a tungsten lamp is about 12 lm/W of input power. If one includes power supply losses (approximately 30 percent), the overall conversion efficiency is 20 lm/W, which still is substantially better than that for the incandescent lamp. In addition, the effective intensity concept expressed earlier leads to an alerting effectiveness that is greater by approximately a factor of 3 for a given flash energy. This suggests that the xenon lamp has an overall advantage of a factor of 5 to 8 in terms of basic power efficiency. The lamps described here use that improvement to permit a substantially greater beam width, primarily in the vertical direction. In practice, the xenon light on which the curves of Figures 3 and 4 are based had a peak effective intensity of 1020 cd for a 20-J input. Two such lamps, each of which would be flashed 48 times/min (a standard rate) and have a total power-conditioning efficiency of only 50 percent, require 32 W, which is little more than the 25 W required for an incandescent light. And significantly fewer lights would be required at most crossings because of the broader coverage.

Flash Rate

A lower flash rate could reduce power consumption to a value equivalent to that for the incandescent case. However, this is undesirable in view of the enhanced alerting effectiveness generally attributed to higher repetition frequencies (45 to 60 flashes/lamp/min as a minimum). Traffic signals normally are operated in the 50 to 60 flashes/min range; a maximum of 55 flashes/min is allowed by AAR standards. Fifty-five flashes/min thus appears to be a reasonable nominal value.

Application Considerations

Direct replacement of incandescent grade-crossing lights with xenon units as has been described is a simple process and offers the likelihood of substantially improved performance. However, it would be unwise and unrealistic to seek widespread use of

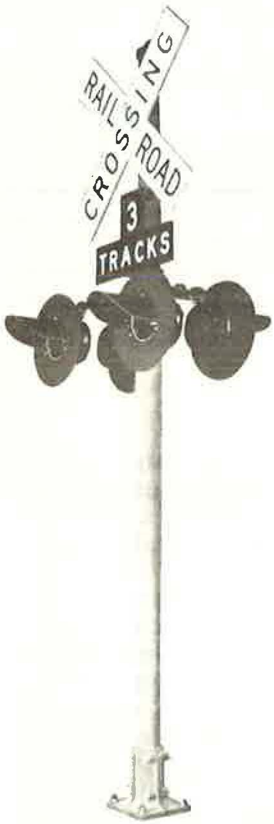


Figure 1. Conventional grade-crossing flashing light.

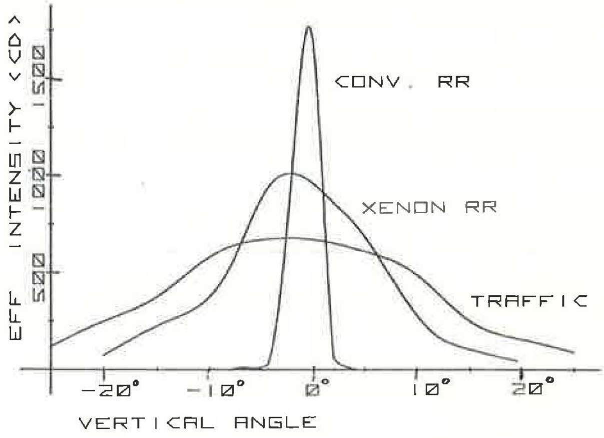


Figure 2. Measured beam patterns in vertical plane.

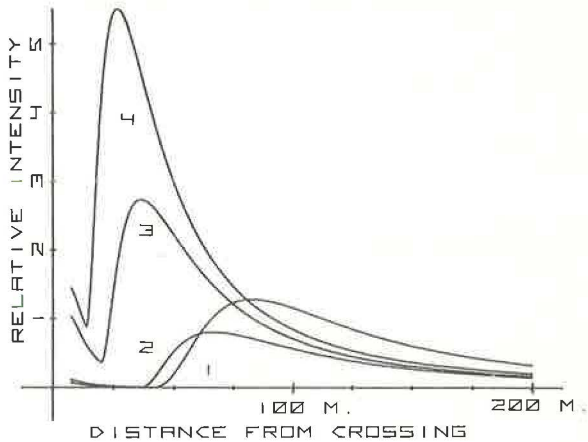


Figure 3. Calculated relative intensity as a function of distance from crossing.

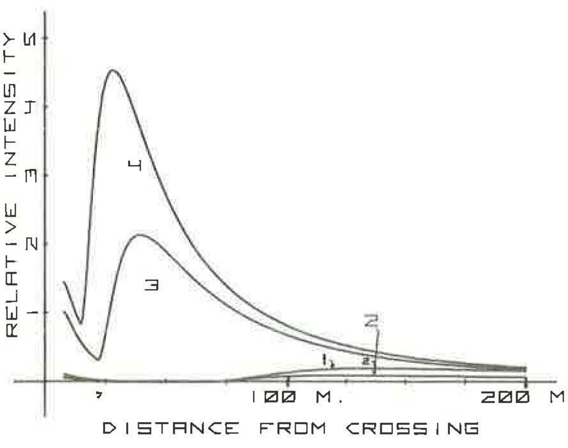


Figure 4. Relative intensity as a function of distance from crossing with lights misaimed 1 deg vertically and 1 deg horizontally.

devices having such a crucial role without first conducting lengthy and comprehensive tests. Fortunately, these lights in no way conflict with existing systems; therefore, xenon lights can be added to crossings now protected with conventional lights. This permits refinement and optimization of all components under practical conditions and allows evaluation of both technical and behavioral factors.

In terms of warning effectiveness, the principal question arising in combined installations is the relationship between the xenon and conventional flashes. With the mounting shown in Figure 5, the simplest possibility (technically) is to attempt no deliberate synchronization; with this, the 2 types of lights will tend to go in and out of phase with each other. This quasi-random pattern can be quite attention getting at some times, but it raises serious questions in a motorist warning system. It can be argued that uniformity of aspect is a key to rapid identification and understanding on the part of vehicle operators and that this is best achieved through ensuring that the perceived pattern is the same every time it is encountered. This can be achieved only through synchronization because different xenon and incandescent flash rates may produce significantly different, asynchronous patterns.

If a synchronous pattern is accepted as preferable, a wide range of choices remain. Several of the more attractive alternatives are shown in Figure 6. Each group of 4 squares represents a pair of xenon flashers above a pair of incandescent units; individual units are darkened to indicate the on state. In each case, a full cycle (flashing of each incandescent lamp) is shown. (The tungsten lamps are on throughout a half cycle; the xenon units fire only at the times pictured.) The different cases are described in terms of the ratio of xenon flashes per cycle to incandescent flashes per cycle; where appropriate, whether the units are in phase or out of phase is noted. Many other possibilities exist. However, those involving more than 2 incandescent cycles in repetition have been found in practice to appear only marginally different from the asynchronous case.

The choice of preferable flash pattern cannot be made yet; it is unlikely that different alternatives will have dramatically different effectiveness. The response of a small number of observers during preliminary studies has shown a preference for the cases of Figures 6a and 6b; Figure 6b provides an X-shaped pattern that is in keeping with the normal grade-crossing symbol. The cases involving flash ratios substantially greater than unity (3/2 and 4/2) require either a relatively slow incandescent flash rate or a high xenon flash rate; the latter is undesirable because of its increased power consumption.

EXPERIMENTAL STUDIES

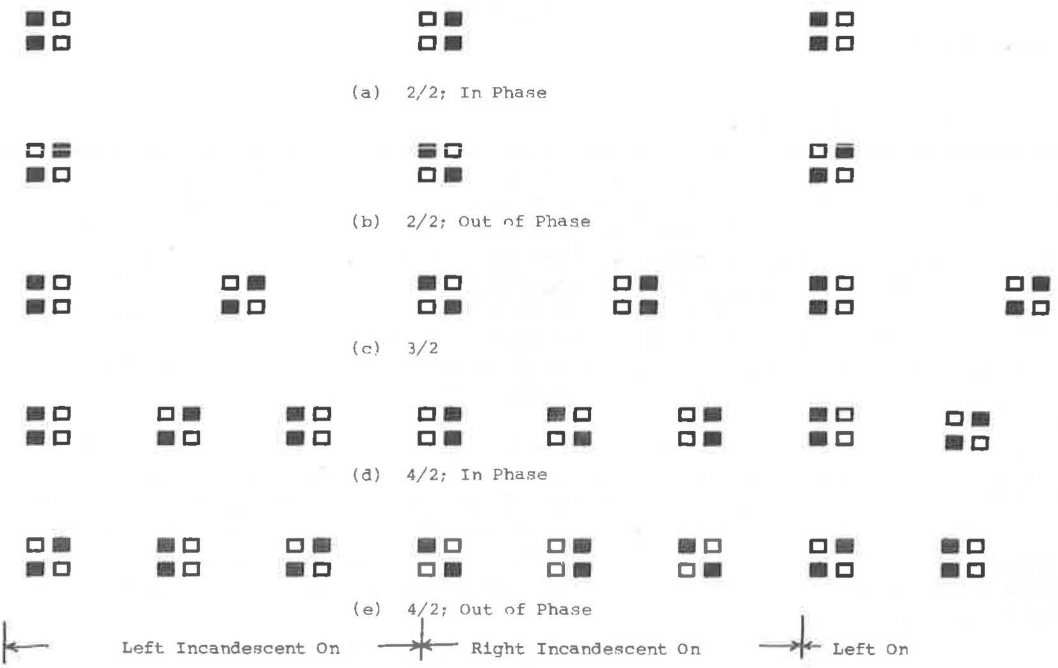
In an area as complex as grade-crossing safety, theoretical analysis and laboratory measurements can be achieved only through extensive experience. As we have noted previously, the Union Pacific Railroad has carried out a substantial test program in recent years that includes installation of xenon flash lamps in a variety of forms at grade crossings in 12 states. Although quantitative measures of effectiveness are not available, the response of most observers is that addition of the xenon lamps provides a dramatic increase in alerting effectiveness and visibility. No major equipment problems have been reported although it is clearly desirable that components engineered specifically for the grade-crossing application would be preferred and would reduce maintenance needs.

To facilitate realistic observation of a wide variety of system parameters, researchers at the Transportation Systems Center prepared a test installation (Figure 5). Results are similar to those reported by Union Pacific. Conspicuousness is high, and the effect of wider beam width is especially pronounced. An additional effect is noteworthy. When an observer's attention is directed not at the flashing lights but near them (a typical situation for a motorist), the short-duration xenon flash appears to be far more attention getting.

The Transportation Systems Center has taken part in installation of prototype xenon lamps at an operating grade crossing. In cooperation with the Bangor and Aroostook

Figure 5. Experimental mounting of xenon crossing lights above conventional lights.

Figure 6. Various alternative flash snychronization patterns.



Railroad, xenon lamps were added to existing protection at a rural crossing near Bangor, Maine. In this case the lamps have been synchronized according to the configuration shown in Figure 6a. Preliminary intuitive observations and comments have been highly favorable. Other installations are planned in the near future to be accompanied by monitoring of equipment operation and community response.

IMPLEMENTATION CONSIDERATIONS

Basic Elements

Installation of xenon lights at an existing actively protected crossing can be a relatively simple operation. In general, all that is required is to raise the crossing sign to permit addition of a second standard junction box crossarm above the incandescent lamps as shown in Figure 5. For a number of reasons, mounting the flasher power supply in a small box at the crossarm is both desirable and convenient. It can be powered either by a special 10-V line from the main equipment case, or, if sufficiently heavy wires are in place, directly from the 10.5 V that drives the incandescent lamps. Synchronization requires only a simple connection. Development of suitable optimized hardware for this application should be a straightforward task that is well within the capabilities of the xenon beacon and railroad signal supply industries. Inclusion of a gelled electrolyte (waterless) battery set in the power package to provide the necessary additional backup emergency supply also should be possible.

Cost

An immediate concern of anyone considering installation of a new warning system component is cost. Although firm figures cannot be reported yet, Transportation Systems Center research has provided sufficient experience to permit reasonable estimates. The flasher heads and mountings, as well as the roundels, are standard railroad units that cost around $100 per pair. The only additions are the sealed-beam xenon lamps and an appropriate power supply, which are likely to represent an expense of around $250 per pair when fully hardened for railroad service. A given retrofit situation may pose special difficulties, but, for cases not requiring extensive rewiring for the heavier load and replacement of poles, labor costs appear unlikely to exceed $500. Incorporation of such lights into a new installation should add little more than the equipment cost.

Installation expense is only one aspect of protection cost. Lifetime and maintenance also must be considered. The only element not identical or comparable to conventional systems is the xenon lamp, which can be expected to have a useful operating life of 3,000 to 10,000 h. If this is achieved in the crossing application, one could expect many years of operation between changes. Crossing maintenance needs therefore should not be increased, and accurate aiming of lights could become significantly less important.

Elaborations and Special Benefits

The greatly reduced need for precise alignment that is associated with xenon lamps can have dramatic benefits with cantilever mountings, which are coming into widespread use. The combination of wide highway lanes and shoulders with rigorous standards for structural rigidity has required development of massive structures, which adds greatly to the cost of protection installations. These mountings contrast sharply with the mountings found satisfactory for normal traffic lights for 2 reasons.

1. Railroad units are designed so that a maintainer can walk out on the arm for bulb changes and aiming.

2. Narrow beam pattern requires that there be no wind-induced movement.

Replacement of conventional lights with xenon units appears to relieve both requirements to the point that normal signal mountings could be used thus bringing about substantial cost savings.

Unlike an incandescent lamp, which requires a specific operating point for best performance, a xenon lamp can readily use a wide variety of energies depending on the capacitor used. Thus a multiple-intensity system in which the brightness of the lamps is automatically determined by ambient light can be implemented easily. One could thereby accommodate the need for particularly high intensity when the light may be seen directly against the sun and low intensity at night (to avoid dazzling the motorist).

FURTHER SUGGESTIONS FOR IMPROVED ACTIVE PROTECTION

The study reported here, as well as investigations by others, suggests that use of xenon flashing lights can offer a significant advance in the effectiveness of train-activated grade-crossing protection. However, this does not exhaust the potential for improvement. There are several respects in which grade-crossing warnings differ from general practices for traffic control devices. It is not the purpose of this paper to analyze this larger situation in detail. However, it is appropriate to outline overall needs and suggest means by which an optimal total system might be achieved.

From the motorist's viewpoint, the first major difference between grade crossings and highway intersections with active protection is the advance warning. For highways, to provide signs indicating SIGNALS AHEAD or symbolic signs showing a traffic light is common practice. For railroads, the advance warning rarely makes any distinction between passive and active crossings even though quite different surveillance activity is required for the different cases. This should be an easy problem to deal with, one requiring only that a reasonably simple set of warnings be adopted and standardized; a number of alternatives already exist (17). In certain cases, particularly those characterized by high vehicle speeds and obscured crossings, active advance warnings are desirable.

A second problem arises when the motorist comes within sight of the crossing. Particularly at night, the distinction between active and passive crossings may remain unclear. Indeed, a recent study shows considerable driver confusion on this subject (5). On the other hand, highway-highway crossings are identified by the presence of a continuous green or flashing amber light. Again, a reasonably simple solution is available; at grade crossings with active protection, a flashing amber light could be provided in the absence of trains. A conventional flashing traffic light, or even a grade-crossing light with an amber roundel would be convenient, but it might conflict with power constraints. (This need not be a serious weakness; absence of the light would both indicate a problem and place a motorist in exactly the same situation as occurs for a dark traffic light or a conventional grade crossing. Thus, emergency power need not be provided for the amber.) One alternative would be a low-intensity xenon lamp operating at a moderate flash rate that would consume only a few watts or less.

A third concern is the dilemma faced by a vehicle operator who is relatively close to the crossing when the signals actuate. At a normal highway intersection, there is a steady amber for 3 to 6 s to indicate that a stop aspect is imminent but that those sufficiently close may pass safely. No equivalent exists at grade crossings, and the resultant ambiguity raises the possibility of an undesirably wide spread in motorist response. Some drivers brake severely, and others simply speed through a flashing red light, which is a poor habit to encourage. The grade crossing may, in fact, be likened to a highway intersection for which the green and amber signals have burned out, leaving only an often-unexpected red signal. For these problems, the shortcomings are easily rectified; a steady amber can be provided for an appropriate interval prior to activation of the crossing flashers. That all of these suggestions are likely to raise concerns about liability and standardization is understood. However, the benefits of bringing active grade-crossing protection into the same general format as exists for other classes of intersections appear well worth the effort, and an increase in protection effectiveness appears almost ensured.

CONCLUSIONS

The analysis, laboratory measurements, and field tests reported here strongly suggest that xenon flash lamps can be employed at railroad-highway grade crossings in a manner that can increase significantly the effectiveness with which motorists are warned of approaching trains. The primary benefit accrues through the increased alerting effectiveness and conversion efficiency associated with short-duration flashes, which in turn make possible the use of a relatively broad beam pattern. Installation of such lights as supplements to existing protection is technically simple, is economical, and should not have any serious liability implications.

Given the optimization of equipment and a lengthy and comprehensive test of the concept, reducing costs and power consumption through elimination of some or all of the incandescent lights may prove possible. In addition, significant improvements are possible through reduction of the severe demands now made on cantilever structures and through simplified tailoring of the light intensity to both crossing location and ambient illumination.

Finally, we hope that this discussion of weaknesses and alternatives will help to open broader consideration of active crossing protection and lead to greater consistency with the proved and recognized principles now applied generally to highway intersections.

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