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ENHANCEMENT OF TRAIN VISIBILITY

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FINAL REPORT

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16. Abstract This report describes a study of the most effective and practical means of enhancing the conspicuity of the trailing end of trains, in order to reduce the possibility of train-train collisions. There are five elements: (a) definition of a usable number of categories of target, background, and ambient conditions which include the great majority of situations actually encountered; (b) estimation of the stimuli required for each category to increase significantly the detection probability for typical observers; (c) examination of all potentially feasible visibility aids in terms of these criteria; (d) determination of estimated costs, lifetime, and power consumption of techniques which appear promising in terms of effectiveness, and (e) delineation of alternative systems, consistent with one another, comprising a hierarchy of effectiveness and cost. Special deficiencies, advantages, and implications for policy which may be associated with particular realizations are indicated. The devices suggested as optimal include large areas of fluorescent material arranged in a distinctive pattern, retro-reflectors at each corner, and flash lamps of moderate intensity. Detailed specifications are given for such aids.

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PREFACE

The work described in this report was performed in the context
of an overall program at the Transportation Systems Center to pro-
vide a technical basis for the improvement of rail operating equipment.
The program is sponsored by the Federal Railroad Administration,
Office of Research, Development, and Demonstrations. The program
supports Government activities designed to promote greater safety
in railroad freight and passenger service.

This study was carried out by a special task force comprising
members of the Mechanical Engineering, Measurements and Instrumen-
tation, and Electromagnetic Technology Divisions of the Transporta-
tion Systems Center. Examination of human factors was the respon-
sibility of H. Hill and E. Sussman. M. Koplow, J. Lifsitz, T.
Newfell, and M. Cartwright contributed to evaluation of optimal
means of implementation. A. Lavery provided overall direction and
review of the project.

CONTENTS

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v

CONTENTS (CONT.)

CONTENTS (CONT.)

ILLUSTRATIONS

ILLUSTRATIONS (CONT.)

TABLES

1. INTRODUCTION

1.1 BACKGROUND

Train-train collisions rank among the most severe accidents associated with transportation. The effectiveness of signal systems, crew performance, and operating rules have made the U.S. safety record in this area an enviable one. However, accidents still can occur with disastrous results. It is incumbent upon all involved in rail safety to seek even more effectively to prevent collisions in the future. One means of contributing to this goal is through enhancing the visibility of the trailing end of all passenger-carrying trains and rail vehicles. ("Passenger" is here used to include both revenue-passengers and crew members.)

The subject of enhancement of visual conspicuity has been studied in the past in a wide variety of contexts. Examples include aviation (navigation aids, obstacle indications, and collision avoidance), maritime activities (warnings, buoys, location of downed survivors), and automotive applications (automobile taillights). In a very closely related area, the Federal Railroad Administration has been exploring the topic of enhanced locomotive conspicuity since 1969, with reference to the prevention of grade crossing accidents. Although none of these areas of past investigation are completely applicable to the problem of trailing-end train visibility, taken as a whole they provide a sufficient background to permit a rapid definition and selection of those techniques which have the greatest promise of providing effective p- tection. This report aims to utilize this information within the special context of rail vehicle characteristics and operating practices, with particular attention to feasibility of application in the railroad environment.

1.2 GENERAL REQUIREMENTS

The fundamental functional requirement on any candidate technique for visibility enhancement is that it be effective under an extremely wide range of "normal" conditions and operating circumstance

at an observation distance of at least one-quarter mile (1320 feet).*
The observer may be assumed to be alert, with primary attention in
the direction of the potential collision object; however, in many
cases he will have no expectation of the possible presence of any
such hazard, and he may be looking for other types of signals,
landmarks, etc. It is most important that the observer be able to
obtain some measure of distance which will also provide an indica-
tion of closing rate. Basic effectiveness should not be seriously
degraded by moderately poor weather conditions, and maintenance re-
quirements must not be excessive, particularly with respect to
cleaning. It is desirable that protection be provided for the trail-
ing end of all trains. In practice, this means that all cabooses,
nearly all passenger cars of whatever type, and most locomotives
could be the subject of visibility enhancement, generally at both
ends. The protection adopted should be unmistakable in meaning.
Further, it should not have a detrimental impact on vehicle appear-
ance.

For passive devices -- those dependent only upon existing il-
lumination -- some guidelines are available as to dimensions nec-
essary for conspicuity enhancement. The literature indicates that
under certain circumstances, there is no significant improvement in
the effectiveness of areas of color if the visual angle subtended
is increased above 20 to 25 minutes of arc [1,2]. At a distance of
1320 feet, this implies a linear dimension of approximately 8
feet. Under normal daylight conditions, an object becomes indis-
tinguishable from an average background at approximately one-tenth
to one-twentieth of this value (see Section 1.4.6) [2]. This,
then, establishes a preliminary minimum value for the overall and
detail dimensions of passive visibility aids. Within the constraints
of this application, effective visibility enhancement is thus pos-
sible, but it will be necessary to choose areas which are as large
as feasible.

Some perspective on the approrriate size of passive visibility
aids can be gained from consideration of Figure 1, which presents

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*This range has been specified as sufficient by the Office of Safety,
FRA.

2

outlines of typical rail vehicles and of several simple shapes. The scale is such that when viewed from a distance of 2 feet (approximately arm's length) they subtend the same angle as would full-size rail vehicles and shapes with 8 and 3-foot dimensions viewed from a distance of one-quarter mile.

1.3 RELEVANT CHARACTERISTICS OF RAILROAD VEHICLES AND OPERATIONS

As can be seen in Figure 2, standard railroad cars and locomotives present great variety within a relatively consistent frontal cross section. Location and size of doors, windows, signal lights, and signs can vary markedly. It is immediately clear that no single shape with linear dimensions greater than 3 to 4 feet could be readily adapted to all cases. At the same time, there is a very large total area, the major part of which is generally available on any given vehicle. Furthermore, the basic dimensions are quite constant. This is particularly true of vehicle width, which is generally very close to 10 feet, with height above the rails commonly 12 to 14 feet for both cabooses and passenger cars.

  (a)   (b)   (c)   (d)   (e)   (f)   (g)
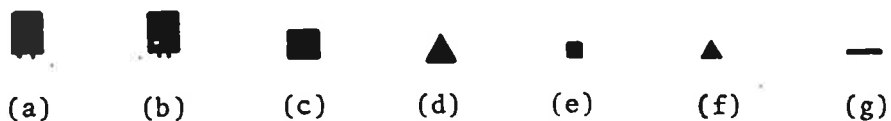
Figure 1. Silhouettes of Relevant Shapes. Angle subtended for viewing at two feet is same as for actual object at 1320 feet (1/4 mile). (a) Passenger car; (b) caboose; (c) 8-foot square; (d) 8-foot triangle; (e) 3-foot square; (f) 3-foot triangle; (g) 1-foot x 10-foot rectangle.

3

Special care must be taken that visibility aids in no way interfere with normal operations, cause confusion, or reduce the conspicuity of existing signals, warnings, or other devices, nor should they have any adverse effect on crew working conditions. For example, high intensity lamps -- steady or flashing -- could cause confusion and annoyance in areas such as classification yards.

A particularly important constraint is the absence of electrical power (other than batteries) in a large portion of the present caboose fleet. While this situation is changing, it will be many years before power is universally available. This limitation does not, of course, apply to passenger cars and locomotives; nevertheless, it remains important to provide substantial protection even when power is lost, lights are burned out or broken, etc.

1.4 BASIC ELEMENTS OF THE PROBLEM

The functional result desired is easily stated: sufficient visual indication to prevent collisions in all cases where this factor is relevant. However, a statement precise enough to permit specification of visibility aids is very difficult to formulate. The aspect presented to the observer is subject to almost infinite variations. A proper perspective on this problem can only be obtained with full understanding of the several interacting elements. The major elements are listed below.

1.4.1 The Target

The object to be detected, in this case railroad rolling stock seen from one end, can be totally clean or obscured to varying degrees by dirt, dust, grease, ice, snow, etc. Numerous car configurations are possible in terms of windows, doors, railings, and other necessary substructures. Even a completely standardized system of visibility enhancement would be subject to shifts in color, contrast with background, brightness, etc., through age or environmental degradation.

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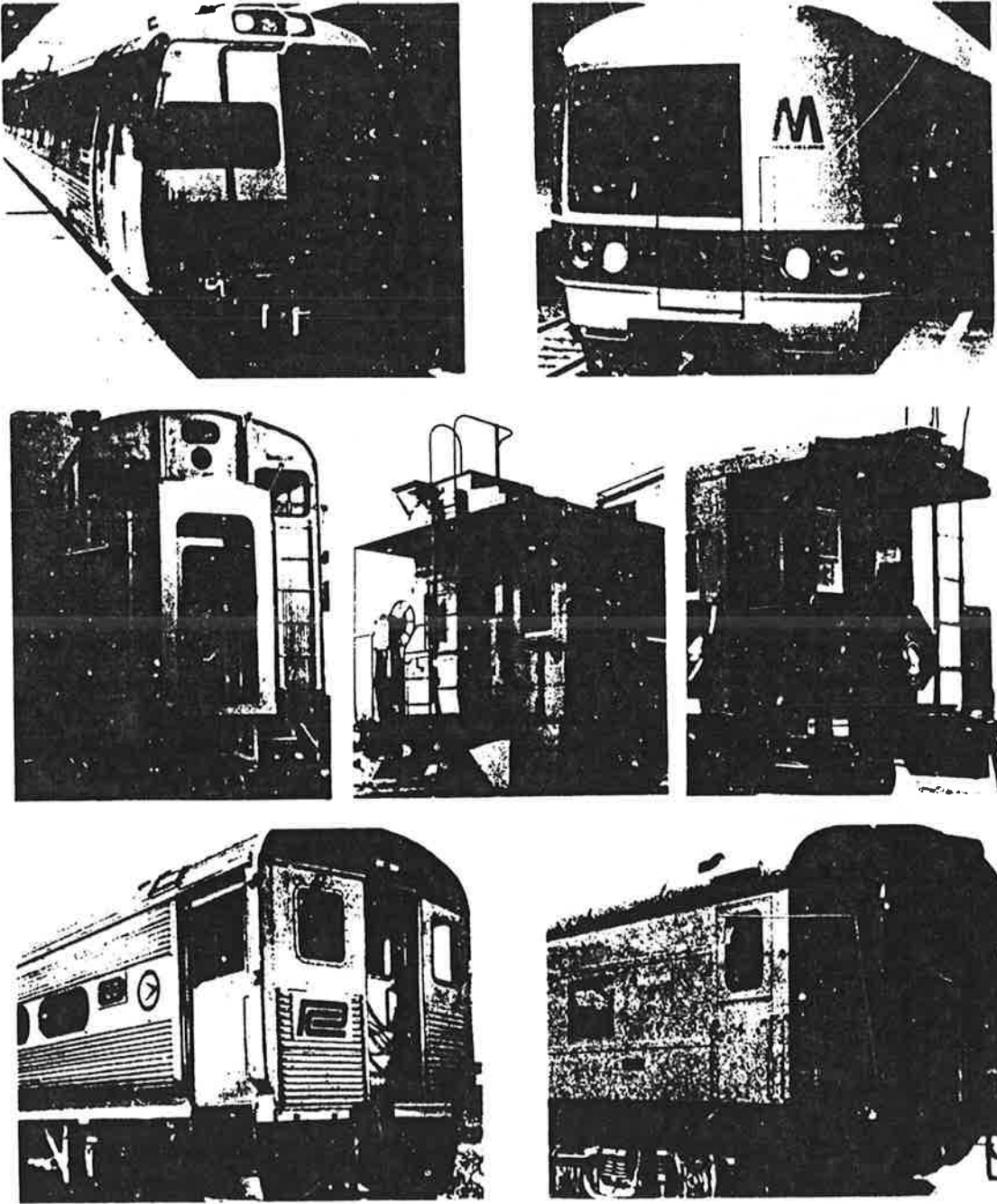
Figure 2. Front and Trailing End of Variety of Rail Vehicles
Reprinted from 1970 Car and Locomotive Cyclopedia
by permission of Simmons-Boardman Publishing
Corporation. Year of first publication 1966.

1.4.2 The Background

Little elaboration should be needed to remind one of the range of visual backgrounds possible: everything from a black night to sunlit snow, with forests, deserts, the full spectrum of urban surroundings, busy classification yards, etc. The background can, of course, include many irrelevant targets or "visual noise," often referred to as "clutter."

1.4.3 Lighting Conditions

Possible examples include strong back or front lighting, high sun, full or partial overcast, twilight, and night, which may be black, moonlit, or illuminated by the glow of nearby lights. A target may or may not be illuminated by the locomotive headlight, which is high in intensity but narrow in beamwidth and which may or may not oscillate.

1.4.4 Atmospheric Conditions

Variations from clear air can cause attenuation and scattering of any light generated by either the target or the observer. Fog can reduce visibility to a very short distance and heavy snow, particularly at night, can be blinding.

1.4.5 Obstructions

Curves or dips in the right-of-way, particularly in the vicinity of buildings, bridges, trees, other rolling stock, may frequently prevent full and direct observation until quite close to the obstacle.

1.4.6 The Observer

The observer of interest is the engineer, and the fireman when present. However, as the fireman is usually an "engineer in training" with similar qualifications, only the engineer's performance will be discussed.

The visual task performed is essentially a vigilance task with

little or no visual search required and with targets originating at or near threshold level. A prime factor in such performance is the visual acuity of the observer. As a majority of the railroads require (or soon will require) visual acuity tests for their engineers, it is to be expected that the range of visual acuity encountered should be truncated when compared to the general population. A likely range is from 20/20 to 20/40 vernier acuity. This means that, in good daylight conditions, the smallest object an engineer should see would be less than 2 minutes of the visual angle (10 inches at one-quarter mile) and would probably be less than 1 minute of the visual angle.

A second major variable in the performance of such a vigilance task is the training of the observer. As the training of engineers emphasizes the visual surveillance of the train, track, signals, and right-of-way, limited variance is to be expected. While factors such as motivation, alertness and fatigue are of great significance, their effect can only be discussed on a case by case basis.

This litany of complexities -- which are generally interrelated -- is not intended to suggest hopelessness. Common experience makes clear that most rolling stock now in use can indeed be made substantially more conspicuous to following trains. Rather, these factors have been cited to emphasize the range of circumstances encountered, and the accompanying need for an array of visual aids.

1.5 APPROACH TO BE FOLLOWED

The determination of optimal means of enhancing trailing-end visibility inherently includes five tasks:

a. Definition of a usable number of general categories of target, background, and ambient conditions which include, to a sufficiently accurate degree, the great majority of situations encountered in practice.

b. Estimation of the stimuli required for each category to increase significantly the detection probability for "typical" observers.

7

c. Examination of all potentially feasible visibility aids in terms of these criteria.

d. Estimation of costs (including hardware, installation, and maintenance) and lifetime, general durability and power consumption of techniques which appear promising on grounds of effectiveness.

e. Delineation of alternative systems, consistent with one another, comprising a hierarchy of effectiveness and cost, with clear indication of special deficiencies, advantages, and implications for policy which may be associated with particular realizations.

Tasks a and b will be treated in Section 2, which establishes the background of human factors information necessary to the overall effort. Tasks c and d are discussed in Sections 3 and 4, in which visibility aids are subdivided into passive and active embodiments. Although the number and range of relevant parameters defy meaningful quantitative measure, and while cost and durability information can only be estimated, it is useful to attempt a semi-quantitative characterization. The method used here will be highly approximate. Normal operating conditions are assumed to be describable in terms of five categories, each taken as applicable a specified percentage of the time:

TIME	PERCENT
Night (locomotive illumination of target)	20
Night (no illumination other than ambient)	30
Day, sun, back-lighting	10
Day, sun, front or side lighting	20
Day, significant cloud cover	20
	100

It is felt that this very crude breakdown provides sufficient accuracy for the intended purpose.

Next, the effectiveness of a given visibility aid is quantized and charted in qualitative ranges: "ineffective," "poor," "good,"

and "very good." This is illustrated in Figure 3, for a hypothetical case. This format indicates qualitatively the level of effectiveness under various conditions, as well as the relative importance of these conditions.

Sections 3 and 4 also include findings and estimates for the component and installation costs, maintenance requirements and expenses, and lifetimes of the devices considered. Given the brief time-frame of this study, it is not possible to obtain high accuracy in these factors, but meaningful guidelines can generally be developed. The results of Sections 3 and 4 can then be presented in a chart of the form shown in Figure 4, in which each candidate visibility aid, or combination of aids, can be characterized.

Effectiveness and durability will here be indicated only in qualitative terms; approximate values will be estimated for cost and power consumption.

Section 5 of this report will summarize such findings, and include task e, the deliniation of techniques considered optimal at
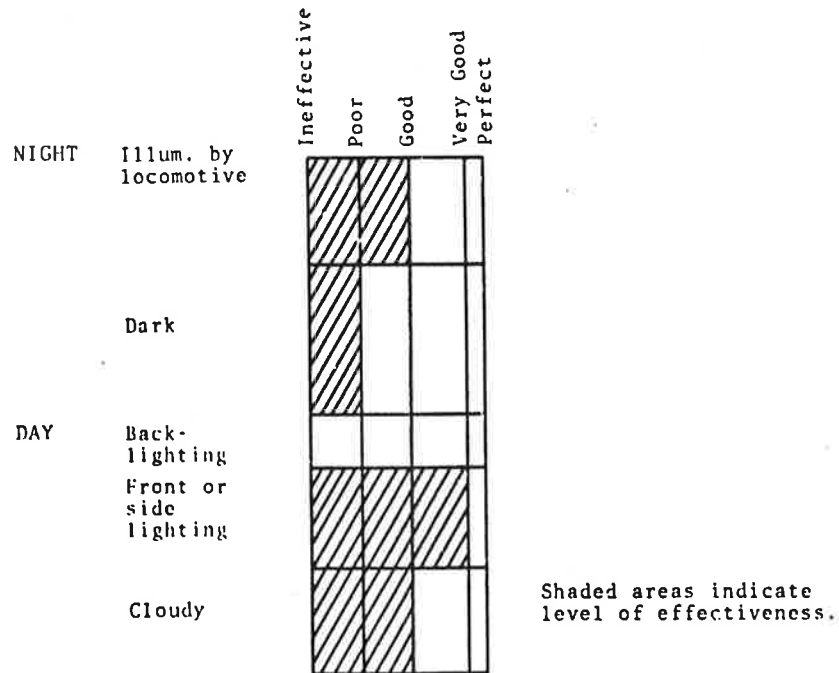
Figure 3.   Sample of Effectiveness Chart

various cost levels. Section 6 will indicate the areas in which
more precise information could be obtained by further investigation
at a moderate level of effort and will suggest possible topics for
further consideration. Certain topics are treated in greater de-
tail in the Appendixes. Appendix A deals with the determination of
required reflector and lamp characteristics. Appendix B treats in-
stallation, maintenance, and lifetime considerations, and Appendix
C considers the problem of dirt deposition on trailing-end surfaces.
Detailed operational specifications for recommended visibility aids
will be found in Appendix D.

TECHNIQUE	OVERALL EFFECTIVENESS	COST	DURABILITY	POWER CONSUMPTION
- - -	- - -	- - -	- - -	- - -
- - -	- - -	- - -	- - -	- - -
- - -	- - -	- - -	- - -	- - -

Figure 4. Suggested Format for Visibility Aid Characterization

2. HUMAN FACTORS IN TRAIN VISIBILITY

2.1 THE PROBLEM

An obstructing train and its surrounding environment can be considered to be a visual display system from which the railroad engineer has to extract the information necessary to enable him to decide on the course of action which results in the greatest safety and operating efficiency. Information bearing on the following questions would be of use to the engineer, although f through h are of relatively less interest.

a. Is there a potentially dangerous obstacle "ahead"?

b. If so, what is it, another train, other railroad rolling stock, maintenance equipment, etc?

c. If a railroad train, is it on the same track as the engineer's train?

d. How far away is the obstructing train?

e. What is the closing velocity with the obstructing train?

f. What is the absolute velocity of the obstructing train?

g. Is the obstructing train accelerating or decelerating?

h. Is the obstructing train being viewed from the head or trailing end?

The effectiveness of any display system or system of markings designed to present information required for answers to the above questions will be influenced by the following environmental factors:

a. ambient illumination

b. visual clutter

c. atmospheric conditions

d. obstructions in the line of sight.

The railroad engineer is expected to detect, and avoid a collision with, any obstructions on the tracks of his train. Since his train is restricted to the track, the situation is different

from the visual detection problems commonly found in other modes of
transportation in that the visual field of search is restricted to
the track right-of-way, the path over which the engineer is sure to
be traveling. Further, unlike the detection problem in aviation,
the visual angle subtended by the silhouette of the end of an ob-
structing train, at the required minimum detection distance of ap-
proximately 1300 feet, is well above threshold during daylight hours;
however, the image of such a silhouette would fall entirely within
the fovea which could hinder its detection under nighttime conditions
Finally, the operator's problem is not one of detecting an object
in a relatively featureless visual field, but rather of determining
if one of the features in a complex visual field represents an ob-
structing train. The question then is how to make the trailing end of
the train contrast with its environment.

2.2   AMBIENT ILLUMINATION

2.2.1   High Illumination (Daylight)

Under conditions of daylight when both the obstructing train
and its surrounding environment are highly illuminated, the detec-
tion of the obstructing train would be aided if its tail end were
marked with conventional or fluorescent paint or other material con-
trasting highly with the right-of-way environment. The minimum di-
mension of any pattern should be at least 1 foot, a width which
is approximately twice the threshold value for normal vision (20/20)
at a detection distance of approximately 1300 feet. The maximum
dimension of the target should subtend an angle of 12 minutes of
arc or larger at that distance, to minimize recognition time.

2.2.2   Low Illumination (Nighttime)

Under nighttime conditions, when both the obstructing train
and the surrounding environment are poorly illuminated, the passive
technique with the most promise is the use of retroreflective
paint, sheets or other devices. The use of retroreflectives can
greatly enhance the perception of an obstructing train when it is

used should be chosen and appled so that it aids in the definition of the contours of the obstructive train. The choice of the same hue as the daytime marking system would prevent the use of the retroreflective material from breaking up the pattern and reducing its effectiveness during daylight operation, although this is not of concern if the reflector dimensions are less than 6 inches. Application of the retroreflective material should be such that it will be reflective over the angle generated by curvatures of the track.

For the not-uncommon stiuations in which the locomotive headlight is not aimed directly at the obstructing train, perception of its presence can be enhanced further through the use of active lighting systems, such as xenon flash tube (strobe) lights or flashing incandescent lights. These active lighting systems should also be designed to aid in the perception of the obstructing train by accentuating the contours of its trailing end.

In the case of back lighting, where the environment surrounding the obstructing train is brightly illuminated but the obstructing train is not, the problem is more one of recognition than of detection. Here the obstructing train must be recognized in the clutter. Visibility in clutter can best be increased with an active light system sufficiently bright to provide a favorable contrast with the dimly illuminated surroundings. A very high intensity is necessary to provide effective enhancement under such conditions.

2.3 VISUAL CLUTTER

For an obstructing train to be detected and recognized in a cluttered environment, the marking on the end of the train must be distinctive and unique. These characteristics can be obtained by using pigments of a hue rarely, if ever, found in nature or in general use on man-made objects. Unfortunately, the most suitable hues in terms of discrimination and recognition might well be those that are the least acceptable aesthetically.

The hue selected and the system of markings used for designating the ends of trains should be as nearly unique as possible to prevent

confusion with any other marking system. Because of the distances involved in railroad operations, the marking system cannot rely on details for recognition and transmission of the required information.

2.4 ATMOSPHERIC CONDITIONS

Under conditions of high atmospheric attenuation, where back-scatter is of little importance (as in a smoky environment), passive markings must have high reflectivity to be of value. Fluorescent paint and materials can be effective under these conditions. Under conditions of low attenuation where the main source of illumination is the headlight of the engineer's own engine, the obstructing train would best be marked with retroreflective material. Fluorescent materials which depend on short wavelength light for stimulation will not be effective due to the small amount of short wavelength light from such incandescent sources. Active lighting systems would be of value under such atmospheric conditions, but would have to be sufficiently intense for effective penetration.

Under conditions of low illumination where both attenuation and backscatter are involved, as with fog and snow, only active lighting systems on the obstructing train would be of value to the engineer in the detection and recognition of the obstructing train.

2.5 OBSTRUCTIONS IN THE LINE OF SIGHT

Obstructions in the line of sight are most likely to be due to variations in the grade of the track and curves. With a grade change from +1% to -1% only about one-half of the end car of the obstructing train is visible to the engineer at a distance of 1300 feet. With larger changes in grade, the problem is increased. Thus, it is important that at least a portion of any enhancement system be near the roof-line of the car.

Similarly, the line of sight can be obstructed by curves, cuts, and buildings, etc. Under conditions of high illumination, little can be done to increase the detectability and recognizability of the obstructing train. Under conditions of low illumination, an active light system which produces sufficient scatter should transmit the required information.

2.6 STANDARDIZATION

In order to detect and recognize an obstructing train, the engineer checks his visual perceptions against a frame-of-reference. The simpler the set of perceptions and frame-of-reference, the easier the tasks of detection and recognition. Thus, whatever is used to identify the end of a train should be simple, distinctive, and restricted to use on railroad rolling stock.

2.6.1 Shape

Use of a specific geometric shape is a common and effective means of enhancing recognition and discrimination. A standard configuration is very important in this application. However, the location of lights, signs, signals, windows, doors, and other components on standard rail vehicles is such that unbroken shapes with linear dimensions greater than 3 feet are usable only at the tops of cars if a uniform pattern is to be maintained in all cases. It has been found in other situations that, for a given area, the most effective pattern is square, as opposed to rectangular variations [3]. Since as large an area as possible should be treated to enhance conspicuity, a large overall pattern, consisting of several properly located smaller shapes, is indicated.

2.6.2 Size

The goal of maximum area for passive aids, along with the basic familiarity which all observers may be expected to have with the size of railroad rolling stock, indicates that the basic pattern should be the full width of the vehicle, with approximate delineation of height. A uniform width delineation is particularly important for range discrimination (see below). Within the constraints of vehicle size, a relatively constant height is desirable.

2.6.3 Color

A color which is standard and not widely used for other purposes is needed. However, variations due to age, conditions, and incident illumination will inevitably cause significant variation

of colored areas; therefore, this factor will not be as crucial to recognition as shape.

2.6.4 Point Devices

Lights and retroreflectors (basically point sources) should be utilized in order to exhibit continuity with the basic shape. Such aids must provide explicit indication of width. Thus, if flashing lights are used, at least one should be on each side of the car, and they should flash simultaneously, rather than alternately.

2.6.5 Hierarchy of Visibility Aids

Optimal protection, taking cost and general viability into account, will vary for different types of cars and/or classes of service. Under such circumstances, it is most important that the successively more elaborate systems utilized be as closely related to the simpler realizations as possible, so that all are immediately recognizable as variations on the same theme. Even a relatively inexperienced observer must have no doubt that the two systems imply railroad rolling stock.

2.7 DISTANCE ESTIMATION

The engineer must be able to estimate the distance between himself and an obstructing train accurately. This estimate is best made through the use of markings or other displays which are readily identified and are of known dimensions. The frame-of-reference of size (size constancy) of the engineer enables him to make accurate distance judgments. The horizontal dimension between marked vertical edges of the end of the obstructing train would provide the necessary information if the markings were standardized. The horizontal dimension chosen should represent the maximum practical width possible on virtually all of the rolling stock in question.

The same horizontal dimension should be used with active displays. The minimum active display would then consist of two lights, separated by the standard horizontal dimension, set as close

to the top of the car as practicable in order to maximize the usefulness of the display in undulating terrain.

2.8 RELATIVE VELOCITY

The engineer estimates the relative velocity between his own train and an obstructing train by noting the change in the observed horizontal dimension of the standard width display.

2.9 OTHER CONSIDERATIONS

It is not clear to what extent the knowledge of the absolute velocity and direction of movement of the obstructing train is of use to the engineer. The determination of these requirements should be the subject of research.

In multitrack situations, it would be of value to the engineer to know definitely if a train ahead is, in fact, an obstructing train on the same track on his. However, no visual display currently available is known to aid his performance significantly in the making of this discrimination.

Although it is not clear that the engineer needs to know whether he is facing the head or the tail end of an obstructing train, this information should nonetheless be available to him through the use of the locomotive headlight day and night.

3. PASSIVE DEVICES

3.1 GENERAL CHARACTERISTICS

3.1.1 Color

Three criteria are of special importance with respect to optimal choice of color for area application. Of greatest concern is the distance at which it can be detected. Second, colors not normally found in nature would be preferable. Third, the connotations of the color must be considered [2]. Green, for example, is clearly undesirable on the latter two criteria. Although no color is best for all conditions, the literature is relatively clear as to the preferred status of fluorescent paints in general and of fluorescent yellow-orange in particular [1,2,4]. Studies have shown that fluorescent yellow-orange has the greatest detection and recognition range of any color tested in both sunlit and overcast conditions, regardless of illumination angle and time of day [4]. Fluorescent red-orange ranks significantly lower. The yellow-orange also meets the criteria of being uncommon in nature and of appropriately connoting "caution."

3.1.2 Shape

As indicated in Section 2, pattern will generally be one of the most important means of target identification. A distinctive shape is required. The key requirements to be met are standard width, delineation of a large area or areas, and the placing of markings as high as possible on the car. The minimum width associated with any pattern elements is to be 1 foot. The simplest shape which meets all requirements, including compatibility with a wide range of rolling stock, is indicated in Figure 5. Variation by as much as ±6 inches from this standard 10-foot width would be acceptable, but is to be discouraged. Some contrast within the delineated area is desirable; any region not treated should be as dark as possible.

18

O · RETROREFLECTOR

///// · FLUORESCENT
    YELLOW-ORANGE

OUTER EDGE OF RETRO-
REFLECTORS IS TO BE
WITHIN 6" OF EDGE OF
MARKED AREA.
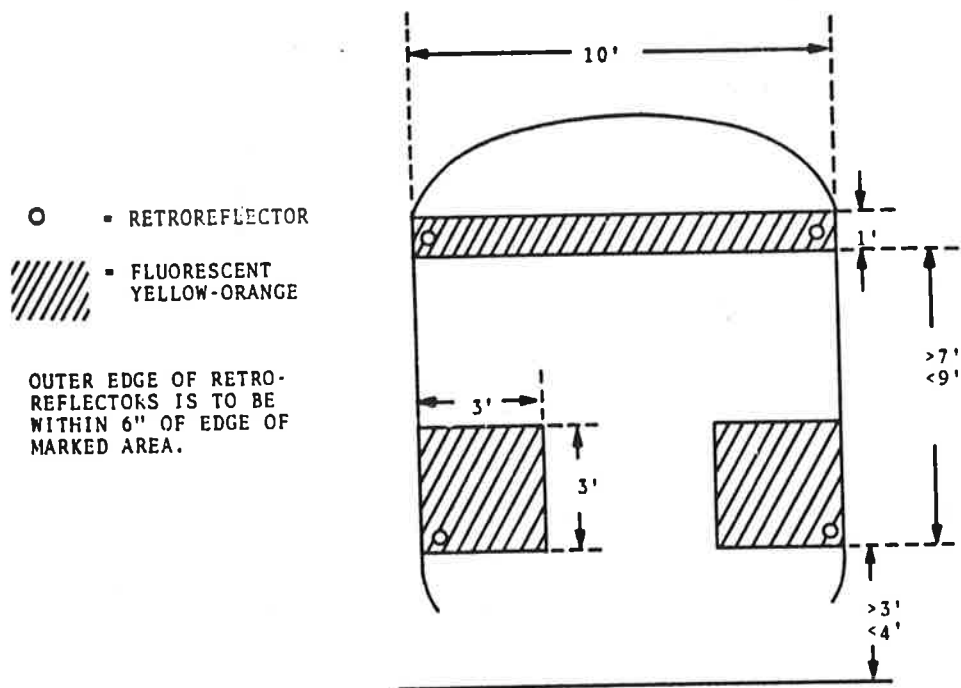
Figure 5. Basic Passive Visibility Enhancement Configuration

3.2 SPECIFIC REALIZATIONS

There are basically three materials available for this appli-
cation, each of which will now be discussed.

3.2.1 Conventional Color

In this case, the most convenient realization is common paint.
It is relatively inexpensive, easy to apply, and quite durable.
However, it can be expected to be effective only under conditions
of strong side or front lighting; this causes it to have a low es-
timated overall effectiveness (see Figure 6).

3.2.2 Fluorescent Color

Fluorescent materials convert incident ultraviolet radiation
to visible reflected light. This provides an apparent reflected
brightness (reflectance) of approximately 300%, or five times great-
er than normal pigments. The requirement for ultraviolet illuminatio

19

rather than visible light, provides a particularly effective display under conditions of cloudiness, shade, or overcast, in which contrast is very low for normal materials. This material is available in a number of hues which are intended to represent particularly effective compromises in terms of visual response, ultraviolet intensity, etc. These materials are now commonly used in highway signing, particularly in providing warning of special hazards, pylons, etc. Figure 7 indicates an estimation of fluorescent effectiveness.

3.2.3 Retroreflective Materials

Retroreflectors are designed to reflect incident illumination directly back at the source, rather than scattering it. Unlike mirror reflection, this occurs for all incidence angles (within a reasonable range). Such materials can be characterized in terms of the enhancement factor (K) which compares the light returned to the source by a retroreflector to that returned by a white perfect scattering surface. This factor is typically of the order of 600 to 1100 for sheet materials, and several thousand for prismatic plastic reflectors. Such devices are very widely used as highway and motor vehicle delineators. A bright reflection is generally found when the observer is within a few tenths of a degree (angular) of the source. A member of the train crew, offset from the headlight by 5 feet at one-quarter mile range, is displaced by 0.2°. Calculations based on a threshold 50 times greater than the FAA criterion, which assumes an actively searching observer, suggests that, for night use with ordinary locomotive headlights, a retroreflective area of approximately 50 square inches is required, assuming an enhancement factor of 1000 (see Appendix A).

A similar calculation for sunny day circumstances results in a required area of 7 square feet of prismatic reflector surface, or 30 to 40 square feet of sheet. It should be noted that retroreflective materials are generally of quite low reflectance off-axis, and would therefore be useful only under conditions of locomotive illumination. It is concluded from this that small retroreflectors
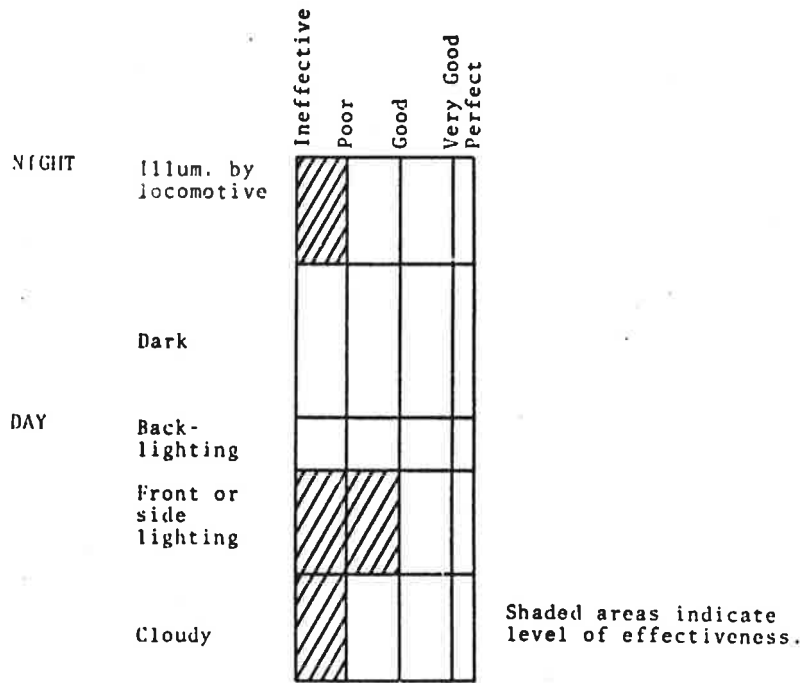
Figure 6. Effectiveness of Conventional Color
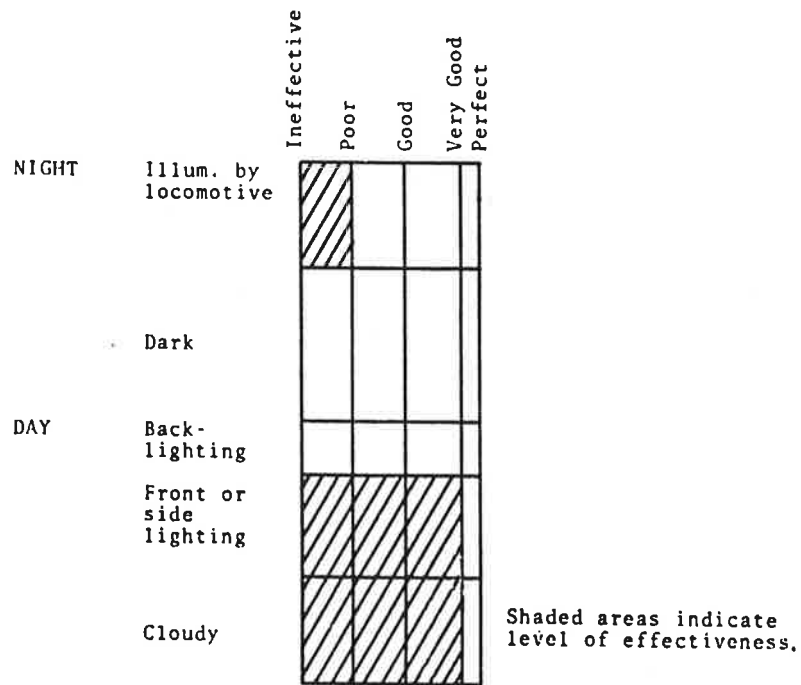
Figure 7. Effectiveness of Fluorescent Color

at night, but that little further is gained by using even quite large areas for daytime conditions. There would, in fact, be a negative effect, since this would foreclose use of other, more effective daytime large-area aids. The anticipated (approximate) effectiveness of retroreflectors is indicated in Figure 8.

3.3 USE FACTORS FOR SELECTED TECHNIQUES

3.3.1 Fluorescent Color

3.3.1.1 Installation - Fluorescent materials are available in the form of paint, coated metal panels, and appliqués. It is likely that each would have advantages in certain cases. The use of panels minimizes complications associated with surface preparation and irregular surfaces. An estimate of $100 to $200 per car including labor seems reasonable, but information sufficient to provide a firm estimate is not yet available. Painting is substantially more complex and expensive.

3.3.1.2 Maintenance and Lifetime - Fluorescent materials depend for their operation on the absorption of ultraviolet radiation. Such radiation is also destructive of the pigments, thus causing a substantially shorter effective life than is found in conventional paints. Available information suggests that the lifetime of such material in this application would be two to three years, although there may be periodic maintenance procedures which would lengthen this substantially. Periodic washing is desirable.

3.3.2 Retroreflectors

3.3.2.1 Installation - Retroreflective material is also available in the form of paint, appliqués, and prepared panels. Installation considerations for these are as indicated above for fluorescent materials. However, plastic reflectors of the type normally used on road vehicles and for highway delineation are of far lower cost. Such reflectors typically cost in the order of $0.10 to $0.50 in
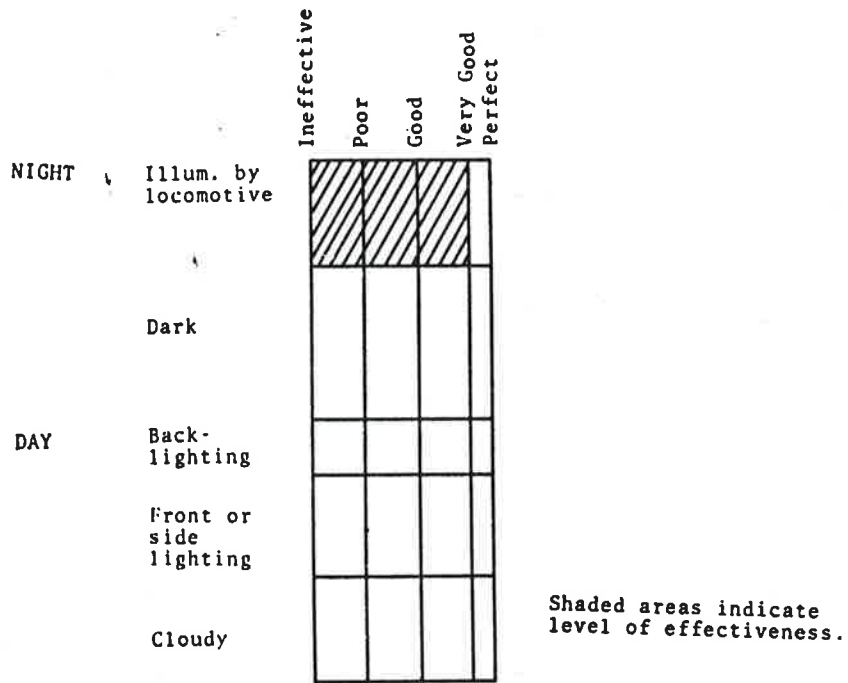
Figure 8. Effectiveness of Retroreflective Material
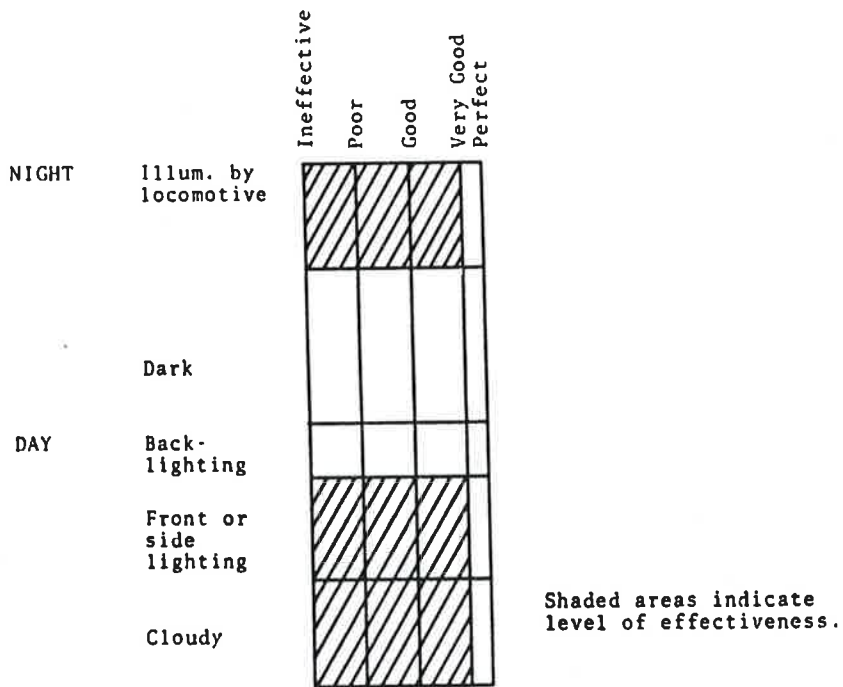
Figure 9. Combined Effectiveness of Fluorescent and Retroreflective Materials

cemented in place, although a variety of mechanical attachment means could be devised. If prepared metal fluorescent panels are used, reflectors could readily be attached prior to installation on the vehicle. It is unlikely that addition of retroreflectors could add more than $10 to the cost of treating a rail vehicle.

3.3.2.2 Maintenance and Lifetime - Outside of periodic cleaning, retroreflectors are virtually maintenance free, and should have a lifetime of many years. Highway experience indicates that they are relatively self-cleaning and retain much of their effectiveness even when dirty.

3.4 SUMMARY

The cases considered are summarized in Table 1. In spite of the possible cost differential, the use of fluorescent material appears clearly warranted by virtue of far superior effectiveness. Although retroreflectors are effective only under limited circumstances, their use is definitely warranted in view of their low cost. Note that these two techniques are complementary, with virtually no overlap in conditions under which they are effective. Thus, the combination appears to be especially valuable, particularly in any totally passive approach. An effectiveness chart for this pairing is included as Figure 9.

TABLE 1. PASSIVE DEVICE CHARACTERISTICS

VISIBILITY AID	OVERALL EFFECTIVENESS	COST	DURABILITY FACTORS	POWER	COMMENTS
Conventional Paint	Very Low	$100	Good	0	
Fluorescent Paint	Fair to Good	$300	Fair	0	Little or no value at night
Retroreflectors	Low	$10	Very Good	0	Very good at night when illuminated

24

4. ACTIVE DEVICES

4.1 GENERAL CHARACTERISTICS

By definition, passive enhancement techniques require a source of illumination -- sun, sky, headlight, etc. These techniques are essentially valueless under some nighttime conditions and in heavy overcast, thick fog, heavy snow, twilight and strong backlighting. These more difficult situations require that the trailing end of the preceding train should provide the necessary visual stimuli unaided. A primary consideration here is that this be accomplished with lighting consistent with the passive techniques necessary for a complete treatment of the problem. The basic requirements of width delineation and minimum likelihood of obscuration referred to previously dictate location of any point sources at the upper corners of the rail vehicles. Thus, roof-mounted beacons are not appropriate for consideration. Lights at the lower corner would also be desirable, but are not expected to add in a major way to the system effectiveness. This is basically a question of additional cost for marginal effectiveness.

Several factors must be considered with regard to color. It is desirable that there be minimal confusion with other signal lights and as much continuity as possible with both the passive visibility aids utilized and with past practices. Since the latter have not been completely uniform, this goal cannot be fully realized. The least confusion and maximum intensity will be obtained with white lights, although amber is acceptable. Red lenses generally attenuate light output by 80% to 90%, so that there is a severe cost in efficiency in using red lights.

It is generally agreed that flashing lights are far superior to continuous beacons in applications such as are under consideration here. Furthermore, flashing lights are usually much less common in rail signal systems, thus reducing the possibility of confusion. The importance of width delineation for range estimation makes it necessary that both lights (or all four, if used) be on simultaneously. The optimal flash rate cannot be determined without further

23

study; approximately once per second is a reasonable starting
point. However, it would be desirable to have a more distinctive
flashing pattern to enhance conspicuity and recognition and to
minimize clutter problems.

The question of required light intensity is not an easy one.
For day effectiveness, particularly in back-lit circumstances, the
required level can be very high. Such intensities may also be too
great for night use and would require some automatic or manual ad-
justment, causing increased cost and implementation problems. As
has been mentioned at several points, the definition of "suffi-
cient" intensity is a difficult question. As for the passive case,
if one takes as the required minimum a value 50 times the
FAA detection threshold (100-mile-candles in daylight, 2 mile-
candles at night) one can calculate required intensity as a function
of atmospheric visibility. Moreover, as a first approximation to
the benefits of flashing lights, it is a generally accepted rule
that a lamp with flash duration less than .2 sec. has the alerting
effectiveness of a steady beacon five times brighter [5,6,7].
(This applies rigorously only at threshold, but is nevertheless a
measure of effectiveness at other levels). Thus, in terms of power
efficiency, the flashing lamp has a five-fold advantage. Table 2
gives calculated required effective intensity for 50 times FAA
threshold, and estimated input power (electrical) for two flash
lamps simultaneously on, assuming one-quarter mile range, for day
and night under various conditions of atmospheric clarity, ranging
from five-mile visibility (clear) to one-quarter mile (very poor).
A 60° x 10° beam is assumed.

4.2 SPECIFIC REALIZATIONS

4.2.1 Delineator Lights

The principal question concerning the realization of suitable
flashing lights that remains to be discussed is that of strobe vs.
incandescent light. It is widely held that, for a given available
energy, strobe lights are the more effective. Since the two de-
vices are really different examples of the same class, the decision

TABLE 2. REQUIRED EFFECTIVE INTENSITY

TIME	VISIBILITY (mile)	REQUIRED EFFECTIVE INTENSITY I_o (cd)	APPROXIMATE INPUT POWER (2 LAMPS) (watts)
Day	5	3,800	17
	1	8,500	37
	1/2	21,800	87
	1/4	150,000	650
Night	5	.8	.04
	1	1.7	.08
	1/2	45	.2
	1/4	300	1.4

must be made on grounds of cost and durability which are treated at a later point.

Such units can provide highly effective aid under unilluminated night and twilight conditions, and enhance conspicuity significantly in the back-lit and heavy overcast case. They can also make a significant contribution at night when locomotive illumination is present. The effectiveness estimated for either strobe or incandescent lights, assuming adequate intensity, is indicated in Figure 10.

4.2.2 Illuminated Panels

A variety of devices are possible utilizing large panels illuminated from the front (viewing side) or, if translucent, from the rear. If utilized, such panels would for purposes of uniformity have to be of basically the form and dimensions designated for the passive three shape display. The practical implications of realizing and maintaining a back-lit panel of this type are sufficiently negative to eliminate the approach, in that it shows no promise of effectiveness greater than can be expected for simple delineator lights.

27
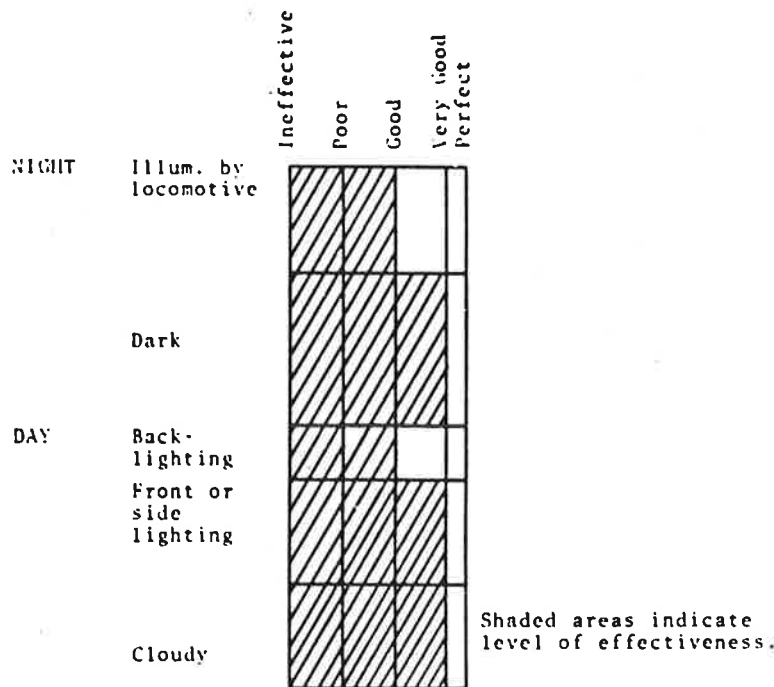
Figure 10. Effectiveness of Delineator Flashing Lamps

The front-lit case is somewhat more interesting, particularly
in the case of cabooses. In this configuration, special lighting is
used to extend and enhance the effectiveness of the previously de-
scribed passive fluorescent display. A fluorescent lamp, inherently
having high ultraviolet output, could then yield useful performance
in virtually all low-incident-light cases. However, efficient im-
plementation of this approach requires that there be a convenient
mounting point 6 inches to 2 feet from the display, and this is
unlikely to be generally practicable. The most convenient case in
this regard is for cabooses and some locomotives. An additional
problem in some instances might be the effect on any crew members
whose duties require them to look in the general direction of such
a light.

The other primary limitation on such a technique relates to
cost and durability. These factors cannot be well defined without
further study, nor can effectiveness vis à vis delineator beacons.

28

It does appear that the power required for a panel is considerably greater that for marker lights. The consensus at present is that illuminated panels are not competitive with the other techniques discussed.

4.3 IMPLEMENTATION CONSIDERATIONS FOR SELECTED TECHNIQUES

4.3.1 Incandescent Lamps

4.3.1.1 Installation - The type of lamps considered here are basically within the typical running light category. In many cases, modification of existing installations (higher power bulbs, clear lenses) might be sufficient. However, installation of from two to eight lamps per car may more commonly be required. This may entail cutting, drilling, running wires, etc. If such systems are utilized in unpowered cabooses, batteries will be needed. It is likely that the cost of the lamps themselves will be a relatively small portion of the total expense, estimated at $300 per car. For short flashes, an incandescent bulb will reach full intensity only for a small portion of "on-time". Thus, the lamps used may have to be rated at higher power then would at first appear to be the case, and efficiency will be lowered.

4.3.1.2 Maintenance and Lifetime - Incandescent bulbs for such applications typically are rated at 500 to 1000 operating hours. Intermittent (flashing) operation can be expected to diminish this considerably. The time which a given system may actually be in use can vary dramatically depending upon the type of service involved. However, in view of the desirability of having all lights working at all times, monthly bulb changes might be required, implying an annual cost in the order of $50. The remainder of the system can be highly durable and low in maintenance expense, unless a battery supply is required. The battery change could add significant expense.

4.3.2 Xenon Lamps

4.3.2.1 Installation - This will differ from the case for incandescent lamps primarily through the cost of the lamp assemblies and required high voltage supply. A very approximate estimate of total cost is $500 per car.

4.3.2.2 Maintenance and Lifetime - Flash tubes are typically rated in terms of the number of flashes obtainable prior to serious degradation or failure. Some are rated in terms of hours of service at approximately one flash per second. In either case, it appears reasonable to anticipate approximately one to ten million flashes. This should translate into one to five years between lamp changes. Power consumption should be comparable to that for incandescent lamps, with similar expenses.
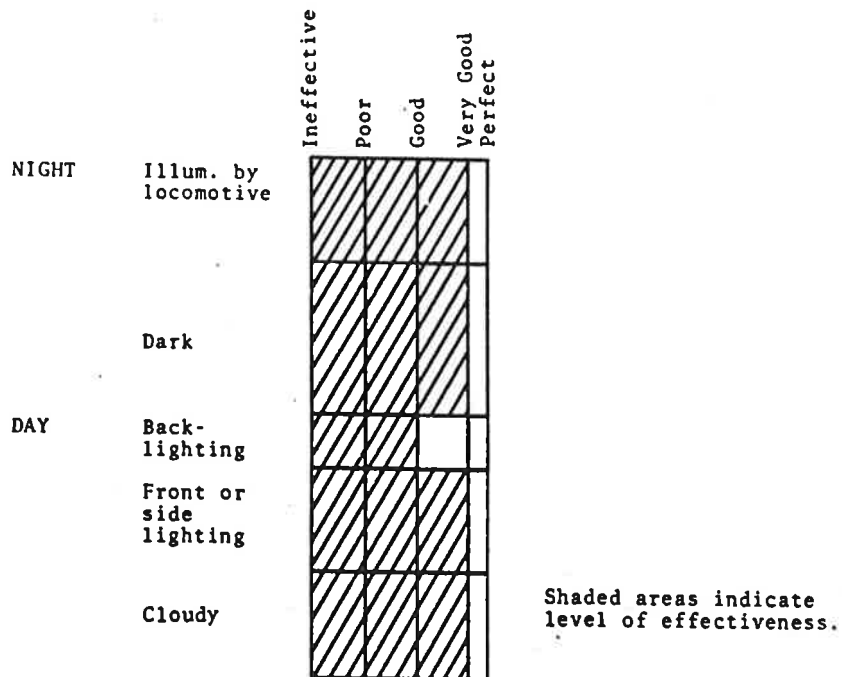
Figure 11.   Effectiveness of a Combined Active/Passive Visibility Enhancement System

4.4 SUMMARY

The results of consideration of active systems are indicated in Table 3. It is not possible at present to make a firm choice between incandescent and strobe lamps. The latter, while of greater initial cost, appear to offer substantially lower maintenance expense and may be significantly more effective. Illuminated panels do not appear competitive under normal circunstances. The effectiveness of a combined active/passive system is suggested in Figure 11.

TABLE 3. CHARACTERISTICS OF ACTIVE DEVICES

VISIBILITY AID	OVERALL EFFECTIVENESS	COST	DURABILITY FACTORS	POWER	COMMENTS
Illuminated Fluorescent Paint	Fair to Good	$750	Fair	20-50 watts	
Incandescent Lamps	Good	$300	Poor to Fair	10-40 watts	
Xenon Lamps	Very Good	$500	Fairly Good	10-20 watts	

5. CONCLUSIONS AND DISCUSSION

Earlier sections have indicated the extreme range of parameters and the large number of contending means of visibility enhancement. However, the necessarily brief but systematic study described in this report has made possible the definition of the two simple, compatible, alternative techniques described below and summarized in Table 4. A number of questions, beyond the acceptability and desirability of the suggested alternatives, remain and are indicated.

TABLE 4. CHARACTERISTICS OF RECOMMENDED ALTERNATIVES

VISIBILITY AID	OVERALL EFFECTIVENESS	COST	DURABILITY FACTORS	POWER	COMMENTS
Alternative I	Fairly Good	$300	2-3 Years	0	Not effective if unilluminated at night, or back-lit.
Alternative II	Very Good	$800	1-3 Years	5-10 watts	Limited effectiveness in extreme back-lit situation.

5.1 ALTERNATIVE I: BASIC PASSIVE VISIBILITY ENHANCEMENT

This configuration is indicated in Figure 11. The optimal color is fluorescent yellow-orange, and the four retroreflectors at each corner are to have sufficient area to provide a minimum total reflection of 100 candlepower per incident foot-candle. This could be achieved, for example, with a 5-inch diameter retroreflector, and provides (when clean) an intensity 50 times the FAA criterion. If areas of reflective material larger than 0.5 square foot are to be used, the color should match the yellow-orange as closely as possible. The outer edges of the 3-foot squares are to define a width of 10 feet ± 6 inches; the height of the overall pattern

should be at least 10 feet, and it is permissible that the top bar follow the curvature of the roof (as in Figure 12) so long as the stripe width remains at least 1 foot. Lights, signs, and windows may require variations, but a total area of at least 10 square feet should remain. It is recommended that all remaining areas be painted with a dark color to maximize contrast. This configuration can be most economically realized with metal or wood panels coated with fluorescent material.

5.2 ALTERNATIVE II: ACTIVE VISIBILITY ENHANCEMENT

It has been seen (in Figures 7 and 8, for example) that active devices are necessary for a thorough treatment of the problem. This is also the case in many types of inclement weather -- fog, snow, etc. (It is worth noting that under conditions of severe icing or wet snow, the only enhancement aids likely to be effective are those (such as automobile lights) which generate sufficient heat to remain clear.) It has been determined that the optimal means of providing this is through the use of the visibility enhancement measures described for Alternative I, augmented by flashing lamps at the upper corners of the basic configuration, next to (or within) the retroreflectors. (In view of their low cost, these retroreflectors should be retained in Alternative II for situations in which the lamps are for any reason inoperative.) A relatively narrow beamwidth is required -- 10° vertical and 30° to 60° horizontal (adequate for a track radius of curvature of one-quarter to one-half mile). The lights should flash in unison, with a repetition rate of 45 to 75 times per minute, and should be clear (white). The clear lens, introducing no attenuation, is substantially more efficient than any color, although amber would be an acceptable alternative providing some continuity of color with the passive system. The lamp effective intensity at the center of the beam should be at least 4000 candela, with up to 10,000 candela preferable. Xenon (strobe) lights, are definitely preferable in terms of effectiveness and power efficiency, as well as being more easily differentiated from conventional signal lights. Incandescent lamps with flash duration less than .2 sec. are acceptable. A

33

regulatory action could, if desired, leave this detail open, merely specifying effective intensities and flash characteristics.

A reasonable variation would be inclusion of similar lamps at the lower corners of the car. This would entail a substantial cost increase for relatively limited benefits in effectiveness, but is worth consideration. In the event that such a pattern is adopted, all four lights should flash together.

Under fog or some daylight conditions, relatively high intensity is required if such lights are to represent truly meaningful visibility aids. These brightness levels may be higher than is desirable under normal night conditions. Thus, variation on the above system would entail using a two-level system, probably with automatic adjustment. To be worth the effort, the higher intensity should be at least ten times the "normal" lower value -- possibly one-hundred times.

5.3 SPECIAL CONSIDERATIONS

5.3.1 Cabooses

A significant percentage of the existing caboose fleet is without power. Although most new cabooses do have generator/battery supplies, it will be many years before this is universal. Thus, passive means alone (Alternative I) are primarily of concern in this case. However, an effective lighting system could be obtained which requires only a few watts of power. If turned off when not needed, a modest battery supply could provide operation for several weeks, at least, and possibly months. Another factor worth serious consideration is enhancing the visibility aids in Rule 99 situations, in which trailing-end protection is specifically required. This could take the form of panel illumination by electric lanterns, increasing marker light intensity, or even changing the flash rate. (This would not, of course, replace any of the currently required actions, but would merely supplement them).

34
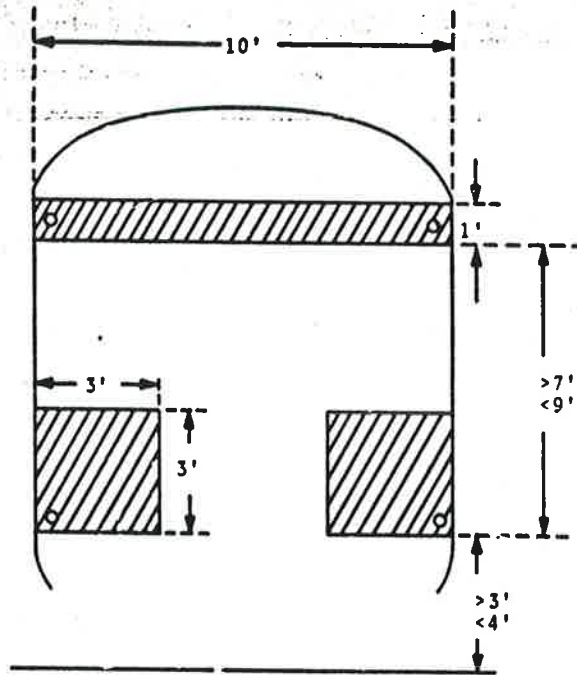
Figure 12. Basic Form of Alternative I Visibility Enhancement
Indicated on AAR Standard Contour for Passenger Cars
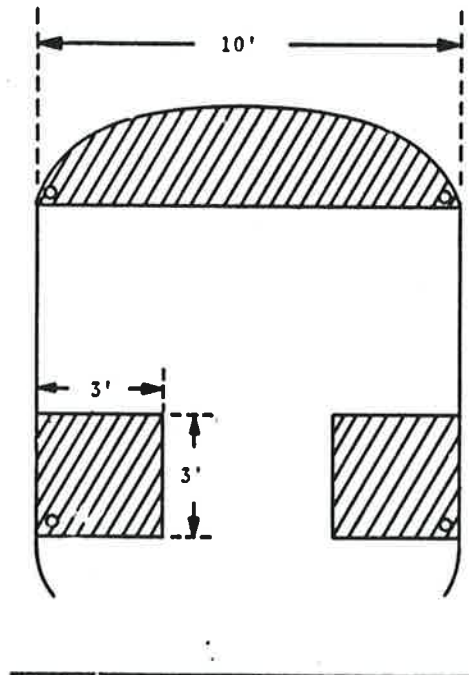
Figure 13. Variant Form of Alternative I Visibility Enhancement

5.3.2 Passenger Cars

Passenger cars are typically operated under conditions of far shorter headways than pertain to general freight movements, and often at higher velocities. The potential number of injuries associated with an accident is ten to one-hundred times greater than for other situations. Finally, the cars themselves are relatively expensive initially, and the expense of visibility enhancement becomes a small percentage of the total investment. For these reasons, it appears desirable to provide Alternative II enhancement for passenger cars, all of which have more than adequate power available. Indeed, a system involving at least two intensity levels appears quite reasonable. It should be noted that present practices, or modest revisions in operations, might make it possible to ensure that only a portion of the fleet would ever be in a trailing position and require protection. This would further reduce overall implementation expense.

5.3.3 Locomotives

The locomotive presents some special problems. In view of the numerous occasions on which trains pass one another, it is most important that the front of an approaching locomotive should not be confused with the trailing end of a train. On the other hand, a locomotive placed at the rear of a train, or traveling unaccompanied, is as important to protect as any other vehicle. The headlight, of course, can provide such front-end delineation, but this depends upon non-operation of the rear-end headlight. This problem is essentially one of policy, for one could simply choose a different form of enhancement (for example, marker lamps in each corner) with no passive delineation. These marker lights could be readily turned on and off as appropriate. In any event, realization of the recommended passive fluorescent markings will be somewhat more complicated on the irregular contour of many locomotives. A different fluorescent color could be used. Strong yellow-green ("chartreuse") might be desirable on power units as an effective means of discrimination; it is also somewhat more acceptable aesthetically. Many locomotives and MU cars see service as head and tail-en

vehicles alternately, so that a readily deployable marking system is necessary. This is a characteristic of Alternative I, which could be realized with hinged panels, roller-mounted fabrics, detachable plates, etc. The importance of this problem is dependent upon the circumstances under which visibility enhancement is required; the question becomes much simpler if only units formally identified as trains are involved.

Another consideration relevant to this question is the parallel desire to enhance locomotive visibility with respect to motorists in order to minimize the probability of grade crossing collisions. While the cases are similar, there are also important differences, since the grade crossing encounter typically involves partial frontal view, with retroreflectors useless and active devices required for low-light conditions. The degree of conspicuity necessary is substantially greater, since the motorist is often neither expecting nor looking in the direction of the train. This subject is currently under examination. However, it is important that the train-train and train-vehicle cases be considered as interrelated, and a common solution sought. For example, an array of strobe lights could be used as described earlier for the trailing-end case, and with higher intensities and a different flashing pattern (alternately, perhaps, with a shorter interval) for the head-end situation and for activation at grade crossing whistle-boards.

5.4 COMMENTS ON SYSTEM SPECIFICATIONS

The time available for this study has not permitted a comprehensive review of the terms or characteristics appropriate to explicit specification of the visibility aids proposed in the two alternatives. It is, to some degree, a policy question as to how completely and rigorously one might wish to prescribe the systems to be used. However, narrow specification of many parameters -- color, light intensities, etc. -- can be readily achieved by reference to existing military, FAA, SAE, or industry specifications. Examples of such specifications are included in Appendix D. Requirements on dimensions can only be made exact with a more thorough examination of the existing fleet of rolling stock.

6. TOPICS APPROPRIATE FOR FURTHER STUDY

While the scope of this study has proven sufficient for the development of alternatives which are very likely to be near-optimal, there are a number of areas in which further effort could beneficially be expended.

6.1 REFINEMENT OF IMPLEMENTATION INFORMATION

The limitation imposed by time has been felt most sharply in the area of developing cost, maintenance, and lifetime estimates for various realizations. The numbers used in this report are conservative. Although preliminary engineering design is involved, this is largely a matter of obtaining information from manufacturers and users.

6.2 XENON AND INCANDESCENT LIGHTS

It is probable that a relatively brief study could resolve the remaining question concerning the most cost-effective implementation of flashing lights, whether strobe or incandescent.

6.3 BEHAVIORAL TESTING

A moderate amount of testing the response of various observers to the different systems proposed or discussed would aid the refinement of device parameters. A large-scale study in this area is probably not warranted, but simulations under a variety of lighting and background situations would be of considerable value.

6.4 RAILROAD INPUTS

Discussions with crew members and railroad safety officers are desirable to highlight the situations which they have found to be most hazardous or difficult, permitting special consideration be to given to such problems. Also, a survey of visibility aids which have been trie' as well as comments on potential

operating problems associated with the solutions suggested here, could be of significant value in system refinement.

6.5 ACCIDENT DATA

Further definition of the more hazardous classes of operation could be obtained from detailed examination of accident data, including Form T records and FRA Office of Safety Railroad Accident Investigation Reports. Delineation of accident likelihood and severity as a function of time of day, weather, visibility, train speed, rail rolling stock involved, class of service, etc., would make possible a far more precise estimate of the potential effectiveness of visibility enhancement and of the situations for which special consideration is appropriate.

6.6 LOCOMOTIVE CONSIDERATIONS

Section 5.3.3 raised a number of questions concerning application of visibility aids to locomotives and MU cars. Further examination of the ramifications of various alternatives would be of use.

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APPENDIX A

OPERATIONAL SPECIFICATIONS FOR REFLECTORS AND POINT SOURCES

By J. Lifsitz

A.1 RETROREFLECTIVE MATERIALS

Retroreflective (or reflex reflective) materials have the property of reflecting incident light directly back at the source, even for large angles of incidence. Thus, they have a very high apparent reflectivity when compared to a diffuse reflector and are not restricted by the normal-incidence requirement of a true mirror. However, effectiveness requires that the observer be very close to the source of illumination -- within a few tenths of a degree, as seen from the reflector. Variation of reflectivity with this angle (the "divergence angle") is indicated in Figure 14 for a typical example. Reflectivity is also dependent on the angle of incidence, but this function is much milder. Also, the narrow beam patterns associated with locomotive lighting make this consideration of little concern here. Retroreflective materials are very commonly found in highway signing and delineation and on the newer automobiles. They can be obtained in the form of paint, sheet, tape, and plastic devices. When appropriate illumination is present, the effectiveness of these devices can be quite dramatic.
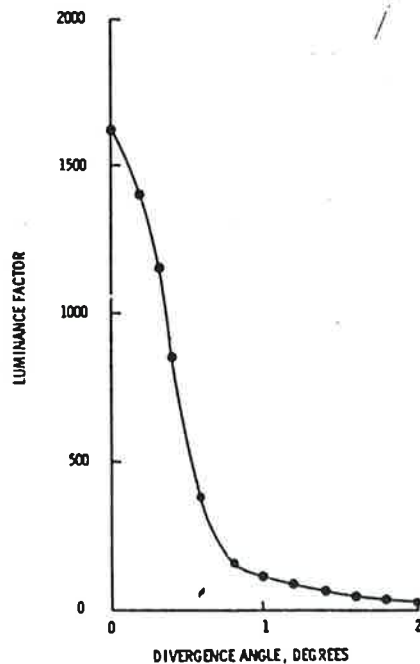
Figure 14. Variation of Reflectivity with Divergence Angle for Typical Retroreflective Sheet ($0°$ Incidence Angle)

The calculation of reflector size will now be considered, particularly as applied to the use of retroreflective sheeting.

If the principle of retroreflection is employed in a target configuration, one must ascertain how large this target needs to be for the reflected illuminance at the operator's eye to meet some detection criterion. Such a criterion depends on operational conditions to such an extent that only reasonable estimates can be made here. One of the factors which influence the value of the detection threshold is <u>background luminance</u>. This may vary from ambient interior lighting at night, through twilight and up to bright haze. <u>Operator preparedness</u> is another such factor. An aircraft pilot, for instance, searches hard for a well-defined pattern on landing, but only for a short, concentrated period; a train operator cannot be constantly searching for a signal ahead and must be alerted by the signal: the threshold for the latter will probably be somewhat higher than for pilots.

The problem of threshold in the present case is difficult even without taking account of atmospheric visibility. If turbidity is also considered, the contribution of atmospheric backscatter on the effective background may be the overriding factor in threshold evaluation. And, as has been previously discussed, extraneous lights in the field of view ("clutter") will have a deleterious effect on the specific detectability of a retroreflecting target. Notwithstanding these constraints, the necessary calculations are relatively simple, and can serve as a useful estimate. Two alternative forms can be used, depending on the parameters specified for the material. The incident flux Φ on a reflector of area A_R, for a source of intensity I_0 at a distance R, is

$$\Phi = I_0 \frac{A_R}{R^2}$$

For a perfect diffuse reflector, the reflected luminance I_R is

$$I_R = \frac{\Phi_T}{\pi}$$

46

For a given retroreflector, I_R is larger by an enhancement factor K (which is a function of both divergence and incidence angles).

$$I_R = \frac{K\phi_T}{\pi} = \frac{KI_o A_R}{\pi R^2}$$

and the illuminance received by the observer at the source is

$$E_R = \frac{KI_o A_R}{\pi R^4}$$

Solving for A_R,

$$A_R = \frac{\pi R^4 E_R}{KI_o}$$

The FAA night detection threshold, based on considerable study, is an illuminance of 7.17×10^{-8} foot-candles (2 mile-candles); for this application a value 50 times larger will be used. A typical locomotive headlight has an intensity of 100,000 candle power, so for R = 1520 feet and K = 10,000

$$A_R(K=10^4) = 5 \text{ sq. in.}$$

A K of 1000 would imply

$$A_R(K=10^3) = 50 \text{ sq. in.}$$

Commonly available sheeting is rated at K ~ 1000, indicating that a 7 in. square or 8 in. circle of such material would be satisfactory.

An alternative way of characterizing retroreflective material is in terms of the specific brightness, which is the candle power returned per unit area of material per foot candle of incident illumination. The reflected illumination E_R at a distance R is then

$$E_R = \frac{BA_R E_i}{R^2} \quad,$$

where E_i is the illuminance at the reflector,

$$\frac{I_o}{R^2}$$

Thus,

$$E_R = \frac{BA_R I_o}{R^4} ,$$

so, as before,

$$A_R = \frac{R^4 E_R}{BI_o}$$

It can be seen that $B = \frac{K}{\pi}$, or $K = \pi B$.

In comparing sheet and plastic materials, several factors are relevant. For very small divergence angles (0.1° to 0.2°) discs can yield very much higher K (or B) values. The Massachusetts Department of Public Works standard at 0.1° is a B of 2000, corresponding to K = 6300 (color: clear). On the other hand, the sheet material can offer much less sensitivity to incidence angle. It is important, for example, that the reflected intensity be as great for an observer at 1/10-mile as at 1/4-mile. Yet, for an observer 5 feet from the source, the divergence angle will have increased from 0.2° to .55°. The reduction in range, which is raised to the fourth power and is approximately a factor of 40, must then compensate for the drop in K (or B) associated with the angular increase. In summary, the basic requirement upon the retro-reflective material used is that for a divergence angle of 0.2°, $A_R B$ = 109, or A_R = 109.8/B sq. ft. = 15,700/B sq. in. (B in candle power/square foot/foot-candle). Thus, a B of 100 requires an A_R of 1.1 sq. ft.; B = 800 permits use of a 5 in. circle. The decision as to which means is preferable for implementation can be based on cost and durability considerations, so long as this criterion ($A_R B$ = 109) is met. Practical values indicate that a 5 in. plastic

48

disc or a square foot of sheet would be satisfactory.

Useful operation in daytime would, by FAA criteria, require a threshold 500 times greater than for night use, and therefore an area 500 times larger. This is clearly not practical.

The use of a threshold 50 times the FAA criterion is based on several considerations. First, this represents an adjustment to operator circumstances -- the FAA criteria relate to the case of a pilot actively seeking runway lights, with a very brief time for detection. Second it provides a margin for equipment degradation and poor atmospheric visibility. Finally, it extends the effective range of the system. The R^4 dependence in the above equations means that under perfect conditions the observer will be exposed to light at the FAA intensity threshold when he is 0.66 miles from the target.

A.2 POINT LIGHT SOURCES

A.2.1 Steady Sources

The visibility of point sources of light depends on several factors, of which the more essential are source intensity, distance, atmospheric visibility, and background luminance. In addition, given a background of lights ("clutter") from which a certain source is to be identified as present, the color, pattern (of several source lights) and flash-rate and duration will be important.

For the moment, we will only consider the visibility of a steady light source, seen under several common conditions of background and atmospheric turbidity. In a succeeding section, an evaluation of flashing lights (particularly zenon flash tubes) is presented. The numerical estimate which follow are not to be taken as rigorous, due to the inherent complexity of the subject.

Allard's law gives the luminous intensity E at a distance D, for a source of intensity I_o, under conditions where visibility is subject to atmospheric extinction (e.g., fog):

49

$$E = \frac{I_o}{D^2} e^{-\sigma D}$$

Here σ = extinction coefficient and $e^{-\sigma D}$ represents the atmospheric transmittance over a path D. For present purposes, the following gives a working relationship between σ and visibility V: $\sigma \approx \frac{3.9}{V}$. This is known as Koschmieder's law, and is actually applicable to the visibility of extended objects contrasted against uniform backgrounds. Nevertheless, since visibility is often estimated in just this manner, the relationship seems useful here.

The value of luminous intensity E which is barely discernible depends primarily on the background luminance. The illuminance threshold (E_t) varies over about six orders of magnitude for backgrounds ranging from starlit to sunlit fog. Measurements of E_t have been made and/or discussed by many (Blackwell, Knoll et al., Middleton). There are many subtleties involved in interpreting the results and particularly in applying them to practical non-ideal situations. The FAA has arrived at a "day-night" assessment of threshold illuminance to be used at airports for landing aircraft. These values will be used here for want of a better choice. They are:

$$E_t = \begin{cases} 1000 \text{ mile-candles (daytime)} \\ 2 \text{ mile-candles (nighttime)} \end{cases}$$

$$(1 \text{ mile-candle} = 3.8 \times 10^{-7} \text{ lumens/m}^2)$$

The nighttime value seems to correspond to a "twilight" situation, according to the data of, for example, Blackwell. This is probably due to the anticipation of a background of artificial lighting near cities, as well as significant ambient lighting of the cabin. Both these situations may also typify railroad operation.

Using the above threshold values, we can determine the required light intensity for various values of atmospheric transmission. For the calculated values shown in Table 5, D is taken to be 1/4 mile and $I_o = E_t[\exp(3.9D/V)]D^2$

TABLE 5. REQUIRED INTENSITY

TIME	VISIBILITY (mile)	REQUIRED STEADY INTENSITY I_0 (cd)
Day (E_t = 1000 mile-cd)	5	76
	1	170
	1/2	437
	1/4	3000
Night (E_t = 2 mile-cd)	5	.15
	1	.34
	1/2	.9
	1/4	6.0

A.2.2 Flashing Sources

The concept of effective intensity is useful in comparing flashing sources with steady ones. The effective intensity I_e is defined as the intensity of a fixed light which has the same signal effectiveness as the flashing light in question.

The effective intensity is given by the Blondel-Rey equation:

$$I_e = \frac{\int_{t_1}^{t_2} I\, dt}{a + (t_2 - t_1)}$$

where I = instantaneous intensity, a is a constant, t_1, t_2 are time limits over which the flash is significant.

We will assume that the illumination due to the flashing source is near threshold for detection. Under these conditions, the constant is generally accepted to be a = 0.2 seconds. (If the light is first seen outside the visual field center, the threshold increases by about 10, with an accompanying increase in the constant a. For the present discussion, the problem of "searching" will not be considered and the railroad situation will be assumed to fall in the center of the visual field.

51

TABLE 6. REQUIRED EFFECTIVE INTENSITY AND POWER INPUT
(Point sources and 1/4-mile detection range
with detection thresholds taken as 50 times
FAA standard levels, for short-flash lamps
and a 10° by 60° beam)

TIME	VISIBILITY (mile)	REQUIRED INTENSITY I_o (cd)	APPROXIMATE INPUT POWER (2 LAMPS) (watts)
Day	5	3,800	17
	1	8,500	37
	1/2	21,800	87
	1/4	150,000	650
Night	5	.8	.04
	1	1.7	.08
	1/2	45	.2
	1/4	300	1.4

For condenser discharge lights (strobes), for which the flash
is very short, the equation can be approximated by

$$I_e = 5 \int_{t_1}^{t_2} I dt = 5x \text{ (total intensity-time integral)}$$

(Note: The underlined quantity is usually specified by manufac-
turers, making computation of I_e convenient.)

The visibility of lamps with short duration flashes can be
determined by using the effective intensity I_e in Allard's law,
as was done above. If the total intensity-time product for a
flashlamp is $I(t_2-t_1)$ candela-second, it has the visual effective-
ness of a steady intensity $I_e = 5I(t_2-t_1)$ candela. Under many
circumstances, some of which are applicable here, the factor of
5 can be increased to the range of 10 to 50. For a flash
rate of one per second, $I(t_2-t_1)$, represents the total luminous
power emitted per unit solid angle. For example, an intensity-
time product of 100 cd-sec, emitted into 1/6 stearadian (approxi-
mately a 10° x 60° beam), represents a luminous power radiation of

100/6 lumens. Typical lamp conversion efficiency is approximately
15 lumens/watt, so electrical power consumption is 1.1 watts.
The effective intensity of this light is that of a steady beacon
of at least 500 cd. Table 6 is an expansion of Table 5 adding an
estimate of the electrical energy required to fire two flash lamps
once per second, illuminating at 10° x 60° area at the specified
intensity, based on a threshold 50 times the FAA criterion. In
this case, the factor of 50 implies an intensity equal to the
FAA threshold at a range of 1.8 miles.

APPENDIX B

INSTALLATION AND DURABILITY
OF VISIBILITY AIDS

By M. Koplow

B.1 INSTALLATION CONSIDERATIONS -- PASSIVE DEVICES

B.1.1 Conventional Paint

The purpose of conventional paint as presently employed on railroad rolling stock is to protect the steel structure from rust. Paints are used for more decorative purposes on some locomotives, passenger cars, and "billboard" cars (i.e., cars which carry advertising). Most conventional paints in use on railroads are inexpensive (as low as $3 per gallon) alkyd base, air drying systems. They have a service life of up to seven or eight years.

More colorful paints used today for logos and decorative markings are generally more expensive, with prices ranging up to $20 per gallon for two-part urethane formulations. Color retention specifications are generally quite loose and are not taken to be an important factor in paint selection. Railroads generally have their own unique paint specification which may or may not include a color or brightness performance specification. An example cited by one manufacturer was "40% gloss retention after three years."

Paint application on railroad stock is usually a spray operation, although any conventional application method may be used. Properly formulated conventional paints can be applied in one coat, or two coats with a short time interval. In either case, the painting of the entire end of a caboose, or large areas of a locomotive should require no more than about one-half man-day. However, this is simply an estimate which does not account for actual railroad labor practices. It is possible that labor requirements may be greater than estimated.

B.1.2 Fluorescent Paint

According to one of the major manufacturers of fluorescent paints, the proper application of these paints requires a 1-mil base coat of flat white acrylic paint, followed by a 3-mil coat of fluorescent paint (done in two separate applications with a nominal 20 minute or greater interval) and a 1-mil coat of ultraviolet-absorbing protective paint [8]. The outer protective layer of paint

also provides a smooth, tough, glossy finish to the surface of the fluorescent paint. Without the outer coating, fading of the fluorescent paint is accelerated and the paint surface is quite easily soiled. Fluorescent paints have a matte finish which picks up dirt easily.

The purpose of the white undercoat is to provide a bright reflective surface under the fluorescent paint. As the fluorescent paint fades, its opacity, as well as depth of color, is reduced, and the base color shows through. A dark basecoat would produce a less acceptable low brightness surface after long exposure to sunlight.

The cost of fluorescent paint is modest. The most popular acrylic (lacquer-like) air-dry paints cost less than $11 per gallon and yield about 250 square feet of coverage. Any good quality basecoat white paint can be used. This type of paint typically costs $4-6 per gallon and yields in excess of 400 square feet of coverage. The protective coating paint costs less than $5 per gallon and will yield over 400 square feet of coverage. Total paint material cost is thus about $0.07 per square foot. The cost of application labor can be expected to be about three times the cost of applying conventional paint, since three coats are required for the first application. Subsequent repainting may be less expensive due to the possibility that the base coat can be omitted.

B.1.3 Reflective Coatings, Appliqués, or Pressure Sensitive Coatings

Reflective coatings for exterior application are marketed in two basic forms [9]. The plastic-based composite sheets are available with a dry, heat activated adhesive or with a pressure sensitive adhesive. The former material can be purchased from secondary processors bonded to sheet metal stock suitable for highway signs or on thin gauge sheet metal rolls.

Two quality grades of reflective material are available from the principal manufacturer: "High Intensity Grade" at approximately $2 per square foot and "Engineer" grade at approximately $1 per square foot. One quality grade of fluorescent appliqué material is

available at approximately $0.50 per square foot.

A reflective paint, actually a paint containing a quantity of glass beads in suspension is also available. The paint is a one-coat system which can be applied by spray or by any other conventional paint application process. The product is sold by the pound costs about $1.20 per pound and provides about 15 square feet coverage per pound at a cost of approximately $0.08 per square foot.

B.1.4 Reflector Disks

Plastic reflector disks may be applied with either mechanical fasteners or adhesive. Small size reflectors (up to approximately 3 inch diameter) may be satisfactorily applied by a single central fastener. These reflectors usually have an integral metal backing which provides a protective raised edge around the perimeter of the disk. The single central fastener can be a pop-rivet, sheet metal screw or nail. Larger reflectors must be secured around their perimeter using multiple point fasteners and a sheet metal frame.

Small (3 inch diameter) reflector disks cost about $0.20 each, or about $4 per square foot. Larger diameter reflectors are less expensive, but generally require the mounting frame at an additional cost.

Adhesive mounting of disks is also a popular means of installation. Cost per unit with adhesive backing is slightly more than without.

B.2 INSTALLATION CONSIDERATIONS -- ACTIVE SYSTEMS

The installation requirements of incandescent lights and xenon strobe systems are similar, except that xenon sources have a separate power supply which must be mounted within a few feet of the flash tubes. Each xenon flasher installation will consist of a power supply and the requisite number of lamp assemblies, while the typical incandescent light installation will consist only of lamp assemblies. Each system will also require control circuitry to turn the system on and off and in some cases to regulate the intensity of the light.

The use of active lighting introduces the possibility of altering the display as a function of train direction and speed. Such added features will complicate the installation by requiring interfaces to transducers which provide the necessary information for display control.

The installation consists of mounting the lights on the exterior of the vehicle, mounting the power supply (for xenon flasher systems), making provisions for lighting control, obtaining an appropriate power source, and routing and installing the necessary electrical cables and wires. This activity is easily and routinely accomplished during the construction of new equipment. On existing equipment, this type of field modification is much more difficult and involves substantial labor to establish procedures for the large variety of existing equipment. Several skilled crafts are needed to accomplish the installation, check its operation, and provide documentation that changes to the vehicle have been made. It is estimated that the cost of making a two light installation on the end of a rail vehicle would be about $200 to $500, depending upon the type of vehicle and light.

In the matter of equipment costs, incandescent lights have a clear advantage. Incandescent lamps and housing assemblies for railroad application are already commercially available. A two light assembly including lamps, control switch and blinker could probably be purchased for less than $50.

Xenon flasher systems have not yet been used on rail vehicles on a commercial basis. The closest comparable equipment is for highway vehicle emergency lighting. These systems typically cost from $150 to $200 for a single light system, and from $200 to $250 for a two light system (producing about 1200 candelas per unit). The replacement cost of a flash tube (with a one year life) is approximately $20. Storage capacitors (with about a three-year life) cost $10 to $20 per light.

It is possible that a xenon flasher system ruggedized for railroad service and with longer life than units designed for intermittent use on highways will cost more than indicated above.

B.3 DURABILITY CONSIDERATIONS -- PASSIVE DEVICES

B.3.1 Conventional Paint

Increased visibility can be accomplished by painting the ends of trains with conventional paint having color and reflectance which contrasts with the background against which the train is viewed. Conventional paint simply reflects or absorbs incident light selectively according to its wavelength. When illuminated by white light, orange paint reflects more light in the orange and near orange wavelengths than in the blue/green region of the visible spectrum. Incident blue light will be mostly absorbed. Thus, orange paint illuminated by predominantly blue light will appear very dark.

Real surfaces always fall short of perfect reflectance, even for the wavelength of light corresponding to their apparent color. Thus, orange paint will not reflect all the incident orange light, but only a fraction of the incident energy at that wavelength. It is clear that conventional colors reflect incident light selectively (as a function of wavelength) and imperfectly (there is some absorbtion at all wavelengths).

Let us assume that paint of a particular color has been selected to enhance the visibility of a train. The hue and brightness of the paint have been determined to produce satisfactory contrast with the background when illuminated by various light sources. Obviously, no color will be entirely satisfactory under all conditions of background and illumination, but a certain color may be selected as best for an expected set of conditions. Let us also consider the ways in which a conventional paint may fail to deliver its expected performance, that is: how the reflectance and color of the reflected light changes under service conditions.

Under service conditions, painted surfaces may become covered with a variety of substances such as sand, clay, organic particles, soot, oil, and various chemicals. To generalize, these substances can be considered as dirt. Dirt will have its own light reflection, absorbtion, and transmission characteristics. Thin layers of dirt,

such as can be seen on windows, will transmit incident light as well as absorb and reflect it. The transmission of light through an absorbing medium is generally an exponential phenomenon which can be expressed as

$$I(x) = I_o e^{-x/\gamma}$$

where $I(x)$ is the intensity of the light at any distance x through the medium; I_o is the intensity of the light in the incoming surface of the medium; x is the distance through the medimum; γ is the characteristic dimension of the medium, specifically the thickness for which $1/e$ = 37% of the transmitted incident light is absorbed.

This value for γ will of course vary depending upon the composition of the dirt, and will also be wavelength dependent. Light transmitted through the layer of dirt will be either absorbed by the paint, or reflected and partially transmitted back through the dirt and emitted.

Hence, the dirt film has the effect of selectively reflecting part of the incident light, transmitting part of the incident light, primarily of the same color as reflected, and absorbing the balance of the light. In general, dirt has a dark appearance without a predominant color. This means that it is absorbing all colors, and has reduced the overall intensity of the light reflected from a surface. The color reflected from a surface will be the same color as the paint, but will be darker due to the reduced reflection of incident light. When the dirt color is distinct and different from the paint color, each will absorb the wavelengths that the other reflects, thereby giving a darker, less colorful, appearance.

Just as the opacity or transmission characteristics of paints depend upon their depth of color, so too do the transmission characteristics of dirt depend upon the color of the dirt particles. Particle size also affects transmission. A given thickness of small particles will transmit less light than the same thickness of large particles. This is one of the principles behind the

formulation of "one-coat" paint systems. The pigment particles are simply ground to a smaller size.

Thus, the degrading effect of dirt on the visibility of a painted surface was several dimensions. Dirt will always degrade the performance of a paint and almost always decrease the visibility of the painted object against the background. This is especially true when the dirt and the background material are one and the same. In practice, dirt films and coatings can build up to obscure completely the painted surface on which they rest. This is particularly true in the stagnatation region behind the end of the train.

Dirt deposition thickness depends on a great many factors, but primarily on the cohesiveness of the dirt and on the quantity of the dirt in the air. Water increases the cohesiveness of dirt, as does oil. However, water will also wash away dirt already deposited. Obviously, an equilibrium can be reached when each quantity of water deposits as much dirt as it washes away. It is the quantity of dirt contained in the water which determines the equilibrium point.

Several other factors can degrade the optical performance of painted surfaces besides the obscuration by coatings of dirt. Paint may undergo chemical changes due to sunlight which fade or alter colors. Contact with chemicals, such as exhausted combustion products, may change paint colors. Simple mechanical abrasion will wear away painted surfaces, giving them a duller, more textured surface, which will more readily be soiled by dirt. Finally, the paint can be simply worn off by mechanical abrasion. While each of these problems is theoretically serious, they are largely overcome in practice by the highly developed technology of paint chemistry. Paints have evolved primarily as low cost means of providing surface protection and improved appearance for conventional materials in diverse applications. There exists an enormous inventory of commercially available paints which are durable, colorfast, chemical resistant, tough, easy to apply and easy to clean. The cost of these paints is in the range of $0.03 to $0.10 per square foot. The service life is well beyond three years even under adverse

conditions, including repeated washing by strong cleaning agents. By most criteria, paint systems for exterior vehicle applications are considered highly serviceable.

B.3.2 Fluorescent Colors

Fluorescent paints and pigments not only reflect portions of the visible light spectrum, as do ordinary paints, but also absorb light energy from the visible green, blue, and near ultraviolet end of the specturm. This absorbed energy is transformed and emitted as light energy of the same wavelength as the reflected light. Fluorescent surfaces have an apparent intensity greater than a conventional surface of the same hue because the total amount of light being emitted is up to three times greater in some cases. Under natural lighting conditions, fluorescent yellow has greater brightness than a perfect white surface. The brightness of flourescent red-orange and orange-yellow is considerably less than a white surface. However, in most field trials, the overall performance of fluorescent pigments exceeds that of white or any conventional color because of its combination of intensity, contrast, and unnatural hue.

Fluorescent paints obtain their unique color conversion ability from special organic dyes which have the fluorescent property. These dyes are bleached by ultraviolet light so that the performance of fluorescent paints degrades in proportion to the integrated exposure to ultraviolet radiation. Tests have shown that, with proper protection of the fluorescent dyes, the effective life (i.e. a 33% reduction in reflectance) is longer than 2.5 years under conditions of direct solar exposure in southern latitudes. As the fluorescent properties diminish, the paint takes on the optical qualities of conventional paint, with reduced opacity and intensity.

It has been mentioned in some sources that fluorescent paints have a tendency to become obscured by dirt more easily than conventional paints. According to a principal manufacter of fluorescent paints, a protective clear coating must be applied to the normally matte finish fluorescent paint to give it a dirt-resistant

finish. Fluorescent paints will show dirt readily because of the high contrast between the paint and dirt. Older fluorescent surfaces, degraded by ultraviolet light, are likely to be dirtier than new surfaces, thus enhancing the notion that dirt degrades the performance of fluorescent paints disproportionately more than conventional paints. Actually, absorption of light by a dirt film will degrade the optical reflectance of two colors of the same hue by the same factor, regardless of whether one is fluorescent or not. One may speculate as to whether dirt films block the short wavelength light required for fluorescent action. Red, orange, and yellow dirt films will absorb blue light, but such color dirt is not often encountered.

It would appear then that the durability of fluorescent paint systems is similar to that of conventional paint systems, except that there is a predictable degradation of the fluorescent property with exposure to ultraviolet light.

A variety of fluorescent plastics and plastic films are available from several sources. The performance of these materials is similar to that of fluorescent paints. The plastic films have better mechanical properties for avoiding chipping, scratching, and other kinds of abrasion. Their surface is smoother, less porous, and less water and chemical absorbant. As a result they are easier to keep clean than painted surfaces.

B.3.3 Reflector Systems

Two types of reflector systems are considered here. First are reflectorized paints and appliqués such as Scotchlite* and second are plastic reflector disks. Both types of reflectors are widely used in highway applications.

Both of these systems offer excellent nighttime visibility when viewed by an observer adjacent to the illuminating source. These reflector surfaces return a much greater percentage of incident light then most backgrounds and hence present a high contrast-

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*Registered Trademark of Minnesota Mining and Manufacturing Co.

ratio target. Reflection from these surfaces is retroreflective, that is, the light is predominatly reflected back in the direction of the incident light.

B.3.3.1 <u>Panels and Sheets</u> - Reflectorized panels of the "Scotchlite" variety obtain their light-reflecting quality primarily from small glass spherical beads embedded in a sheet matrix material, or contained in a paint vehicle. Each glass sphere acts as a total internal reflection retroreflector. Colors are obtained by bonding transparent plastic sheet, or by applying a transparent dye, over the panel. In either case, the glass beads are not directly exposed to the environment. Material of this type has has been used with success as ACI labels on railroad cars, and on automobile licenses plates. In such applications the claimed useful life of the reflectorized materials has been about five years. Automobile license plates have been shown to be effective for five or more years on a routine basis. Reflectorized highway signs have a service life of over five years.

The optical performance of reflectorized panels degrades in time due to deterioration of the clean plastic film protecting the glass beads. Eventually the beads themselves may be exposed to the environment and their surfaces damaged. Imperfections in the glass surface cause light scattering, and the reflectors lose their retroreflective property.

Reflectorized paints are similar to conventional paints except that the glass beads are held by a paint matrix. The distribution and protection of the glass beads is inferior to that of the reflectorized panels. The paints have a textured surface which is more easily fouled and from which the spheres can be more easily dislodged. The paint systems are, in general, less durable than the panels, and provide inferior optical properties. The presence of water on exposed heads degrades their optical performance greatly.

B.3.3.2 <u>Retroflective Disks</u> - Retroreflective disks (also called reflex reflectors) are flat clear or colored plastic assemblies consisting of a front lens and a backing plate. The lens of the disk is flat on the exposed face, but covered with a continuous array of corner reflectors on the opposite side. Light entering the lens from the flat side is reflected internally by the corner reflectors and directed back in the direction of the incoming light. The backing plate seals the back side of the lens from moisture. The presence of water on the back of the lens would permit light to be transmitted through the disk rather than being reflected.

The performance of these disks can be impeded only by a reduction of the light transmission properties of the lens, by marring of the lens front surface causing it to diffuse incident light, or by mechanical failure of the disk assembly permitting water to collect on the rear of the disk.

The usual failure mode of these disks is marring of the front surface by chemical and mechanical degradation. The color stability of some reflectors (notably yellow) has been questionable in the past. The lens material in most applications is an acrylic plastic which, after prolonged exposure to sunlight, develops an etched chalky appearance. However, under most conditions, these devices have a useful life of many years. Automotive taillight lenses have a service life of up to ten years, but with reduced performance.

Disk type retroreflectors, when viewed and illuminated close to the surface normal are better reflectors than beaded glass surfaces. However, when viewed or illuminated away from the surface normal, their performance is generally inferior.

B.4 DURABILITY CONSIDERATION -- ACTIVE DEVICES

B.4.1 <u>Incandescent Sources</u>

Incandescent light sources have been used on railroads for years with satisfactory results in terms of durability or service life. Light bulbs for railroad service are ruggedized by using

heavier construction than conventional bulbs, and by using a heavier, cooler filament with a lower color temperature. This cooler operating temperature increases the life of the bulbs and its reliability greatly. However, it makes railroad incandescent sources inefficient, especially when blue or green filters are used, since the lower color temperature sources have relatively little green and blue light in their spectrum.

B.4.2 Xenon Flasher Systems

Xenon flasher systems have come into common usage in the transportation field in recent years. They are used routinely now on private and commercial aircraft, on towers, as obstruction warnings, in lighthouse and buoy applications, and as emergency highway vehicle warning lights. A variety of types and sizes are now commercially available from a number of manufacturers.

Xenon flasher systems are inherently more complex than incandescent sources. The light from a xenon source comes from a plasma arc established in a small volume of xenon gas confined in a glass tube. The arc is created by discharging a high voltage capacitor across the gas volume. The discharge of the capacitor creates a short duration, intense light-producing arc in the gas. When the capacitor is discharged, the arc extinguishes, and a power supply recharges the capacitor in preparation for the next discharge. Three elements in the xenon flasher system have limited service life: flash tube, the capacitors, and the trigger transformer. The service life of these components is predictable and sufficiently long to make for practical commercial applications. The length of service life depends upon the stressing of the components. In some applications, a few hundred flashes is a suitable service life. For commercial transportation applications, a few million flashes are required. Service life depends upon the level of electrical stressing and the flash rate. Manufacturers of low cost systems for highway vehicle applications offer a service life of ten thousand hours -- roughly one year of continuous operation. A one-year service life compares favorably with the service life of most incandescent sources.

APPENDIX C

SUSCEPTIBILITY OF THE TRAILING END
OF TRAINS TO DIRT ACCUMULATION

By M. Koplow

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The durability of any device employed to enhance train visibility should be given careful consideration because the railroad environment is severe and hostile to devices of this nature.

The primary mechanism for degrading the performance of train visibility enhancement schemes is the propensity for the tail end of a moving train to become covered with a thick film or deposit of dirt. This dirt (or snow in some cases) will diminish the effectiveness of any visibility enhancement scheme to a greater or lesser degree, depending upon the actual circumstances. For exampl under some snow conditions, only heat-producing sources, such as strong lights, will remain conspicuous on the end of a train. Every other surface becomes covered by a layer of snow and blends quite well with any background snow cover.

The accumulation of airborne particles on the back end of mov ing bodies is a common phenomenon. It can be observed on trucks, buses and, to a lesser degree, automobiles. The cause this phenome is well understood, having its basis in the ability of the airstream to carry heavier than air particles. At the trailing end of a blunt body (such as the end of a truck or train), a highly tur bulent flow-field develops as a result of the air not being able to maintain its (relatively) streamline flow around the abrupt change in body contour. Particles carried by the airstream are deposited on the body because, due to their higher density, their flow path is different than the air flow path.

It has been shown in theory and experiment that particles adjacent to a moving body immersed in a homogeneous fluid remain in contact with the body. But more dense particles, such as dirt or water carried by air, can penetrate this fixed layer of air and deposit on the body.

The dirt deposition problem exists at the front of the vehicle also, but is not as severe because there is less turbulence and the air is cleaner. It is primarily the turbulence at the ground produced by the moving vehicle which introduces the large amount of dirt into the airstream surrounding a moving train. High speed trains are even capable of picking up stone ballast, although no