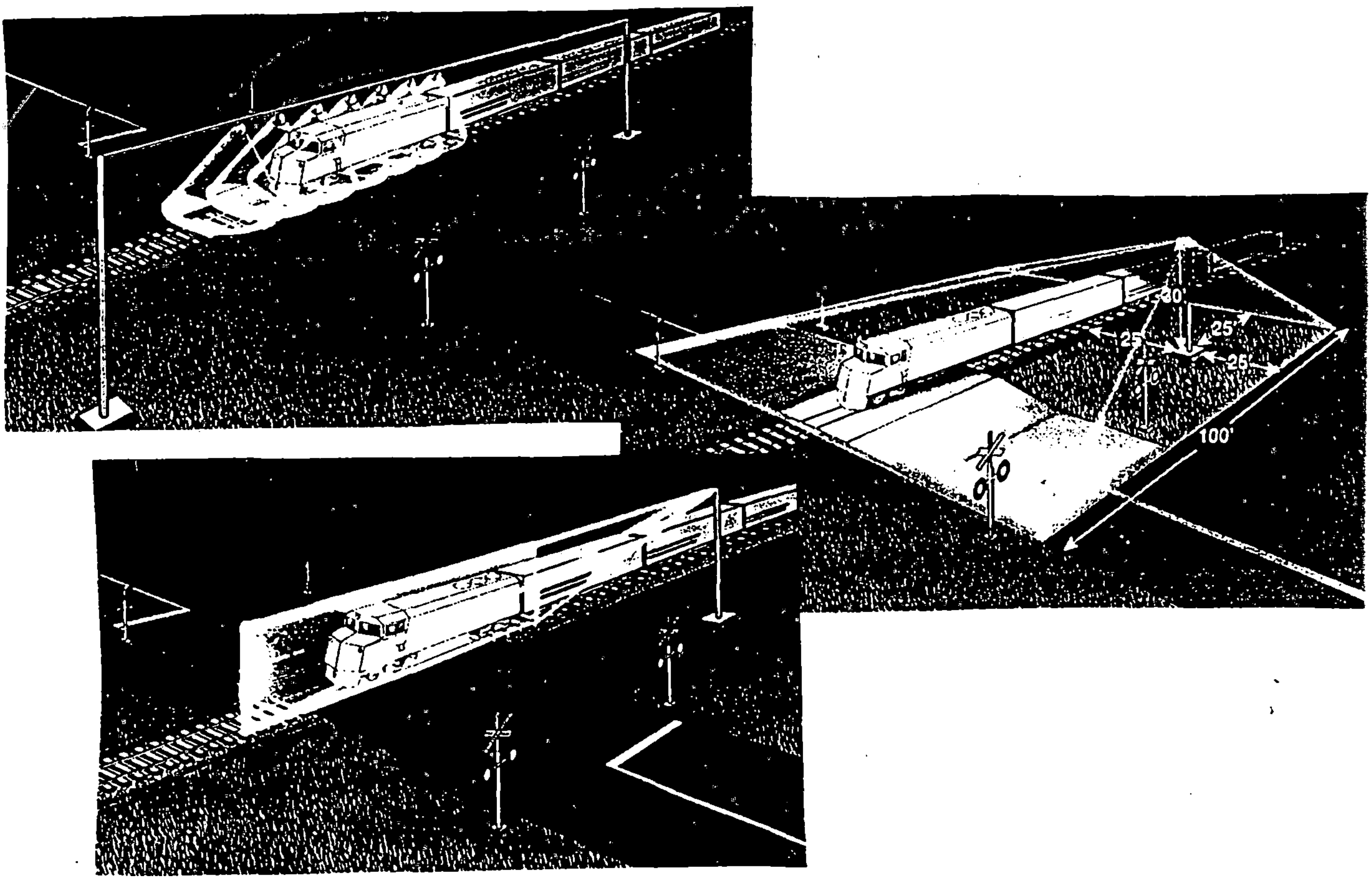
U.S. Department
of Transportation
Federal Railroad
Administration

Safety of Highway-Railroad Grade Crossings

GUIDELINES FOR GRADE CROSSING ILLUMINATION

Dr. Norman Knable



always expect a train

RAIL ROAD CROSSING

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An assessment of the requirements for illumination at a railroad grade crossing reveals two principal needs: the need to illuminate the sides of railroad cars by in-place lighting at the crossing so that they can be recognized by a motorist at a stoppable distance, and the need to provide characteristic lighting of the horizontal crossing area for the purpose of forewarning the motorist of the approach to a crossing.

This paper examines the problem of determining the illumination required for recognizing railroad cars, and presents recommendations for illumination standards and compliance verification. It includes some designs, using available equipment, which can provide the necessary illumination.

It also estimates the cost of lighting installations where electrical power is available and makes some observations on the utility of using stored energy packages where electric power is not available.

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GLOSSARY

candela	Unit of luminous intensity, lumens/steradian.
crossbuck	Pole with crossed signs marking crossing.
disability glare	Glare that decreases ability to perform optical task.
footcandle	Unit of illuminance, 1 lumen/ft^2.
glare contrast factor	Contrast of luminance of task to veiling luminance.
IES	Illuminating Engineering Society.
illuminance	Power per unit area, units of lux.
lambertian scattering	When light falls on a rough surface the scattered light is distributed as the cosine of the angle of its direction of propagation and the normal to the surface.
lumen	Unit of optical power = 1/683 watt.
luminaire	Combination reflector/lamp for specific optical angular coverage.
luminance	Luminous intensity per unit area for a surface, candelas per m^2.
luminous intensity	Optical power per unit solid angle in a direction, candela.
lux	Unit of illuminance, 1 lumen/m^2.
optical task	Detection/recognition of an illuminated object/source.
retroreflector	Corner reflector which reflects light back on itself regardless of the aspect of the reflector.
steradian	Unit of solid angle, a sphere contains 4π steradians.

threshold	Threshold visibility occurs when the illumination parameters permit an observer to detect an object in 50% of a set of decision attempts.
veiling luminance	L_v, angularly weighted luminance from sources of glare, interferes with ability to see on-axis objects.

PREFACE

It is estimated that there are 100,000 highway/railroad grade crossings in the United States where approaching motorists are forewarned only by passive warning signs and crossbucks. Illumination systems may be used at crossings to enhance the motorist's ability to recognize the crossing and railroad cars occupying or passing through the crossing. The low cost of illumination systems, especially where commercial power and street lighting systems are available, has encouraged their use.

These illumination systems serve only to alert a motorist to the presence of the crossing and to the presence of a train, not its approach. Even so, they may reduce auto/train collisions in a cost-effective manner. This report comments on the 1) efficacy of illumination systems and 2) suggests guidelines for their deployment and performance.

This report was prepared by the John A. Volpe National Transportation Systems Center (Volpe Center) in support of the United States Department of Transportation, Federal Railroad Administration, Office of Research and Development, Track Research Division, William R. Paxton, Chief. The author wishes to thank Anya Carroll and John Hitz of the Volpe Center for helpful suggestions.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (k) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

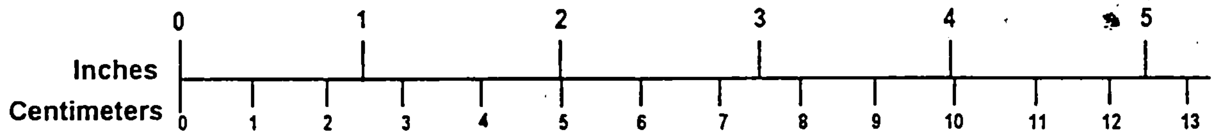
VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

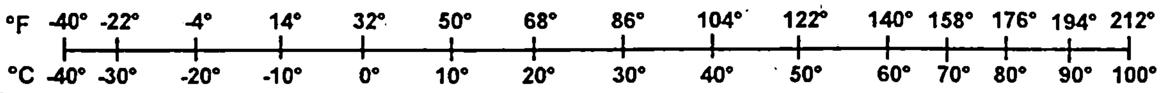
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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EXECUTIVE SUMMARY

Under conditions of poor visibility and at night, in-place illumination at a grade crossing can be used to increase the visibility of the crossing and trains within the crossing to approaching motorists. Illumination of the grade crossing has two purposes: 1) alerting the motorist to the presence of the grade crossing by illuminating the horizontal crossing surface, and 2) illuminating the side of the train to make it visible to the motorist. Acceptable standards for horizontal luminance of the grade surface have already been established at 0.8 candelas/meter[1] by the Illuminating Engineering Society. It remains to determine the illumination level necessary to make the train visible to the motorist.

When the conditions for seeing a train occupying a crossing are ideal, i.e., the automobile headlights are high beam with clean lenses, the road surface is at right angles to the track, and the weather is clear, the illuminance of the train from the automobile at a distance of 200 meters[2] may be as high as 3.8 lux. Higher illumination levels to enhance the visibility of railroad cars can be achieved with in-place lighting. The glare of lights used for illumination on the opposite side of the crossing from the approaching motorist must not appreciably lower the ability of the motorist to make use of the illumination on his or her side of the crossing, thus placing an upper limit on this type of lighting.

The lack of experimental data on the required amount of illumination needed to capture the attention of the approaching motorist and to recognize the railroad cars, leads to the

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[1] See reference 1., pages 14-21.

[2] Two hundred meters is the distance required for stopping an automobile traveling at 60 mph (see reference 9, page 133).

conclusion that the maximum amount of illumination should be used, consistent with available equipment, economic feasibility, and elimination of disability glare,[3] the lessening of the motorist's and the train operator's ability to see a dimly lighted object adjacent to a bright light source. This conclusion is derived from the observation that the threshold contrast required for train detection steadily decreases with increased luminance of the train wall as discussed in Section 3.

Classical visibility experiments, which allow us to calculate detection probabilities for a given illumination and condition of railroad car walls, make a convincing case for illumination of railroad cars in the crossing by in-place lighting. Such installations are especially economical when currently available street or roadway lighting equipment and maintenance organizations are used. To this end it is recommended that an illuminance of 100 lux be present at the railroad car wall in the crossing, installed so as to cause minimum disability glare. This is 27 times as much light as would be available from an automobile at 200 meters with well-aimed, high-beam headlights and clean lenses.

Calculated values for an illumination distribution and installation costs using available equipment are given in Appendix C. The calculations show that it is possible to provide 100 lux at the train wall by using available in-place equipment with an installation cost of less than $6,000[4] and a $1,200 yearly fee for power. It has been assumed that power is available at the site.

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[3] See Appendix I page 5.

[4] See reference 14.

1. INTRODUCTION

It has been observed that during nighttime and low-visibility conditions there are more automobile-into-train collisions than during daytime operations. In this report an investigation of the effect of illumination at grade crossings is made, to determine if in-place lighting can make a significant improvement, over the use of a motorist's headlights, in making a train occupying or passing through the crossing visible. Guidelines are offered for the illumination of crossings to eliminate these car-into-train accidents. Some consideration is also given to the problem of the unavailability of electric power at the crossing.

The following scenario describes the problem. It is nighttime and a highway vehicle with activated headlights approaches a railroad grade crossing which is not equipped with active signals (equipment that senses the approach of a train and presents optical or other signals to an approaching motorist). Passive signs (which may be retroreflecting) have been placed along the highway, sufficiently distant from the crossing and at the crossing itself, to alert the driver. If the signs do not draw the motorist's attention she or he will take no action; if the signs are detected, the common procedure is to reduce speed and look for a train within or approaching the crossing.

There are over 100,000 railroad grade crossings in the United States that are not equipped with active signals. As noted in the Federal Railroad Administration (FRA) Office of Safety, Highway-Rail Crossing Accident Bulletin,[1] approximately one-third of the 762 U.S. grade crossing accidents which occurred at these crossings at night in 1993 were run-into-train (R-I-T). In this report consideration is given to incidents where the train is present in

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[1] *Highway-Rail Crossing Accident/Incident and Inventory Bulletin*, No. 16. 1994, July.

the crossing at a time when the driver can bring the car to a stop before reaching the crossing, but does not detect the presence of the train in time to avoid collision.

The luminous intensity of the high-beam headlights on an automobile can be 150,000 candelas[2] (lumens/steradian). At 200 m (660 ft) a vertical wall would have an illuminance of 3.8 lux (0.35 footcandles). Driver experience and accident statistics verify that under ideal nightime conditions, the presence of a train in a crossing approached by a car is routinely detected by the driver in sufficient time to bring the car to a stop at the crossing. Ideal conditions means the car headlights are on high beam, have clean lenses, and are properly aimed, the car is on horizontal ground and headed at right angles to the train, the walls of the train have a moderately high reflectivity, the speed of the car is not too high and the driver is alert and paying attention to the road ahead.

Other than active crossing signals that warn the motorist of an approaching train, the techniques available to mitigate R-I-T collisions are: 1) railroad car lights, 2) retroreflector- equipped railroad cars, 3) signs and crossbucks, and 4) in-place illumination of railroad grade crossings, augmenting that provided by highway vehicle headlights. Techniques 1, 2, and 3 have been treated elsewhere.[3] The fourth technique is treated in this paper. The use of this technique assumes that railroad cars are sufficiently maintained such that they have a nominal reflectivity (see Appendix A).

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[2] Reference 1, page 16-2.

[3] Farr, E.H. & Hitz, J.S. *Effectiveness of Motorist Warning Devices at Rail-Highway Crossings.* FHWA/RD-85/015.

The cost of providing warning information at a grade crossing is a significant factor in the selection of the warning technique to be used. Retroreflectored in-place warning signs such as crossbucks appear to have the lowest cost. If electric service is available, in-place illumination using available street lighting equipment is more effective in alerting motorists to the presence of the grade crossing and its surface condition and additionally the presence of a train, but at a higher cost. If power from a local utility is not available and must be derived from a solar source or a motor generator, the use of augmenting illumination is more costly. Another factor to be considered in a system using stored energy is the need to detect an approaching train, as the system may not be able to store enough energy to provide continuous illumination. In such a system the additional costs of train detection would make them comparable to those of an active signalling system.

The following six sections and three appendices consider the crossing visibility problem and develop guidelines for enhancement of train and crossing visibility using in-place illumination. Section 2 discusses the need for illumination, assesses present conditions and provides an example of what may be achieved. Section 3 discusses the fundamental processes of visual detection and recognition. Section 4 discusses the nature of glare and its limiting effect on illumination. Section 5 suggests guidelines for illuminating grade crossings. Section 6 describes how compliance with the guidelines may be achieved. Section 7 describes the uses of further experimentation. Appendix A describes the visual performance experiments which led to the guidelines and conclusions contained in the report. Appendix B describes a solar panel/storage battery-powered crossing illumination system. Appendix C describes two computer generated crossing designs. Cost estimates are included.

2. BACKGROUND

Low traffic crossings in isolated areas, while in need of collision warnings have not warranted the expense of an active signalling installation. These crossings have been equipped with passive warning signs (crossbucks) located at the crossings and along the approach to the crossing. Some crossings which are more heavily used are equipped with highway-illumination-type lights which serve to make trains in the crossing more visible to motorists and to illuminate the crossing area.

This report inquires into the effectiveness of in-place illumination and recommends guidelines for crossing illumination. The guidelines will support the functions of making the railroad cars in the crossing more visible, illuminating trackside signs such as crossbucks identifying the crossing to the motorist and any faults in the crossing surface visible to the motorist.

Several papers have been published which attempt to establish the value of illumination at grade crossings, from accident data which were obtained during a period which included data before and after the crossings were equipped with illumination equipment. Of the few published papers which have noted a lessening of the number of accidents after installation, there remains the question of whether the improvement was due to the upgrading of the crossing crossbucks and clearing of obstructions which usually accompanies such installations. Other installations did not show any improvement. Russel and Konz[4] suggest that inadequate illumination is responsible for many nighttime accidents offering, as confirmation, reports that most night R-I-T incidents are mid-consist collisions while most day R-I-T incidents are front-consist collisions.

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[4] See reference 2.

The uncertainties attending accident data are such that reliable conclusions about the usefulness of illumination cannot be drawn from them. It seems clear that illumination of railroad cars in a crossing *can* improve visibility of the train to motorists and lighting of the grade crossing surface area *can* identify a crossing to a motorist. What must be established is the type and intensity of illumination to be used at crossings to give the motorist a high probability of detecting and identifying railroad cars in the crossing and delivering a clear warning of danger ahead by illuminating the crossing surface area.

In a 1990 paper, The Oregon Public Utility Commission reported the costs of installation and maintenance of 34 illumination systems installed between the years 1984 and 1989. Most of the installations were on single track lines using two 200-watt high pressure sodium luminaires, mounted on 30-ft poles with 6 to 16 ft arms. The average installation cost of the 34 crossings was less than $2,000. The monthly maintenance costs averaged $15 per luminaire pole. The costs cited include the poles, arms, and luminaires.

Some cost estimates are made for the computer generated designs described in Appendix C. They are approximately twice the cost of the above designs.

These data show the costs of illuminating a crossing, including inflationary increases, to be modest (where electric power and maintenance service are available), and probably acceptable to most communities.

The distance required for a motorist to stop his or her vehicle after noting a train in the crossing may be calculated from a quadratic function of the automobile velocity. This requires an assumption of the highway/tire coefficient-of-friction and driver perception/reaction time. For average dry road conditions and driver performance, the stopping distance for a 60 mph automobile is 200 meters (660 ft).[5] At this distance as described above, the high-beam headlights of an automobile will illuminate the train with 3.8 lux (0.35 footcandles). A 250-watt high-pressure sodium lamp located at the crossing can illuminate a train in the crossing (without excessive glare to motorists approaching from the opposite direction) with 100 lux. This is indeed an improvement (27 times, 270 times if low-beam lights are used) over headlight illumination and gives the driver an increased chance to detect trains in a crossing.

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[5] Reference 9, page 133.

3. VISUAL ABILITY

The eye being the detector of signals generated by crossing illumination, it is necessary to investigate how it performs this task and how to make use of its sensitivity. Lacking reliable experimental data on measurements of train detection and recognition, in crossing situations, it is necessary to fall back on an analysis based on fundamental visibility experiments reported in the professional literature.[6] These have to do with a viewer's ability to detect an area target (task) against a luminant background as a function of the contrast of the task and background.

The fundamental task from which all other visual tasks are derived is contrast detection. Uniform illumination of the retina does not provide any useful information. The usefulness of the eye lies in its ability to inform about luminous discontinuities and gradients in the visual field. However, the transfer of optical energy from an object to the eye also depends on the size of the pupil which varies for individuals and is a function of the age of the observer. Predictions of visual behavior cannot then be made solely from luminance descriptions of the scene.

The visual tasks to be considered for detection of a train in the crossing are the detection of a railroad car silhouette against a luminous background and the detection of train markings of a contrasting color or shade on the side of the car itself. Although detection of the contrasting markings on the railroad cars will be treated here, detection of the car silhouette will be optimized by the same technique, i.e., provide the maximum illuminance available, consistent with glare from the in-place lights not being

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[6] See Appendix A.

more than 20% of the luminance in the crossing scene[7] as observed by the train operator and the motorist.

In suggesting guidelines for crossing illumination the visual performance relations derived from the fundamental experiments referred to in Appendix A will serve to establish levels for illumination and performance.

It is recognized that under conditions where the observer has not been alerted to the task, his or her response may be very different from that of the participants whose responses are represented by the Visibility Reference Function.[8] Observers are subject to many distracting influences, both external and internal, which will modify their responses, hence the reiterated need for experimental data and simulation.

In cases of faulty headlights, location of the crossing on a curved section of highway, low railroad car reflectivity and low contrast due to dirt or spilled cargo, the additional illumination of the cars by in-place lighting will permit the motorist to detect and identify a railroad car, thereby increasing the chances of averting vehicle-into-train collisions.

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[7] The veiling luminance contrast is a measure of the effect of glare on the observer. The ability of the observer to see is diminished as the veiling contrast decreases. See Appendix A, page 5.

[8] See Appendix A, page A-3.

4. GLARE

The effects of glare from the illumination sources must be considered at 1) the position of the motorist and 2) the position of the train operator (see Figure 1).

1. Consideration of glare is most important at the position where the motorist must first detect a train in the crossing.[9] Subsequent glare as she or he approaches the crossing is a lesser consideration than the handicapping of the motorist at a position that requires maximum visual capability.

2. In addition to the requirement that crossing illumination must not impair the motorist's vision, it must not interfere with the train operator's ability to observe and respond to normal trackside signs and signals, i.e., block signals, switch targets, speed signs, etc. The glare from illumination sources at the locomotive cab must not be great enough to obscure the trackside signs and signals.

Figure 2 shows that at the motorist position requiring maximum visibility, the angle subtended by the distance from the in-place light on the far side of the track and the train wall will always be small since the distance of the illumination source from the task source (train) is much less than the motorist's distance from both. By aiming the illumination source at an angle to the train wall, the luminous intensity of the sources in the direction of the

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[9] While glare is an intuitive sensation, a discussion appears in Appendix A, page 5, which defines its measure and its disability threshold.

motorist and in the direction of the train operator can be less than that which would cause disabling glare.[10]

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[10] See Appendix A, page 5.

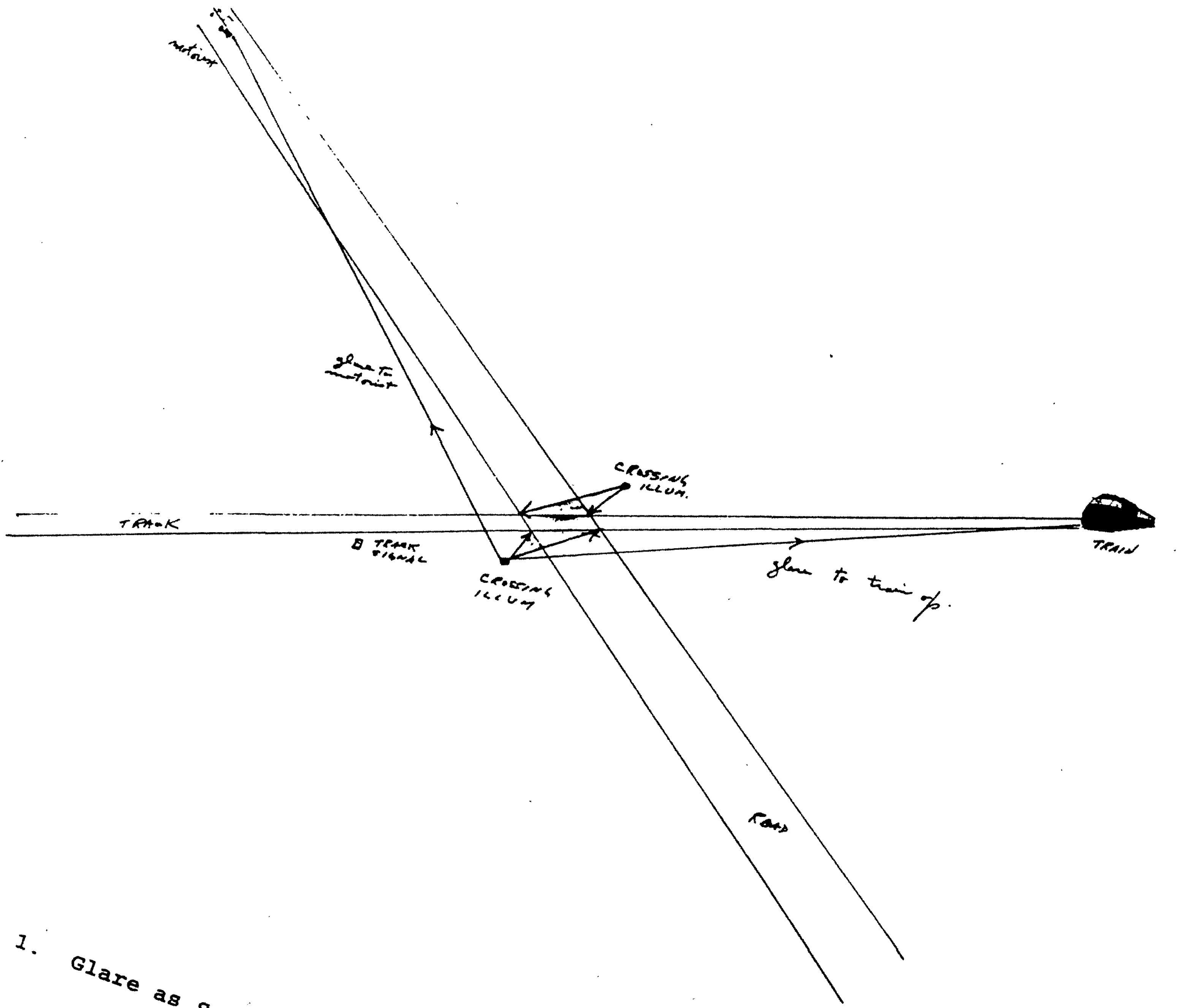

Figure 1. Glare as Seen by the Train Operator and the Automobile Operator

Designers of low-glare illumination systems should be guided by the following rules:

1. Place lighting in an offset position from the observer, mounted on towers. Aim the lights to direct minimum radiation along the highway and along the track.

2. Use fast angular falloff luminaires.

3. If there are more than two tracks, illuminate in depth by successive banks of lights, each close to the illuminated track so that luminaires need not be aimed toward the motorist or the train operator.

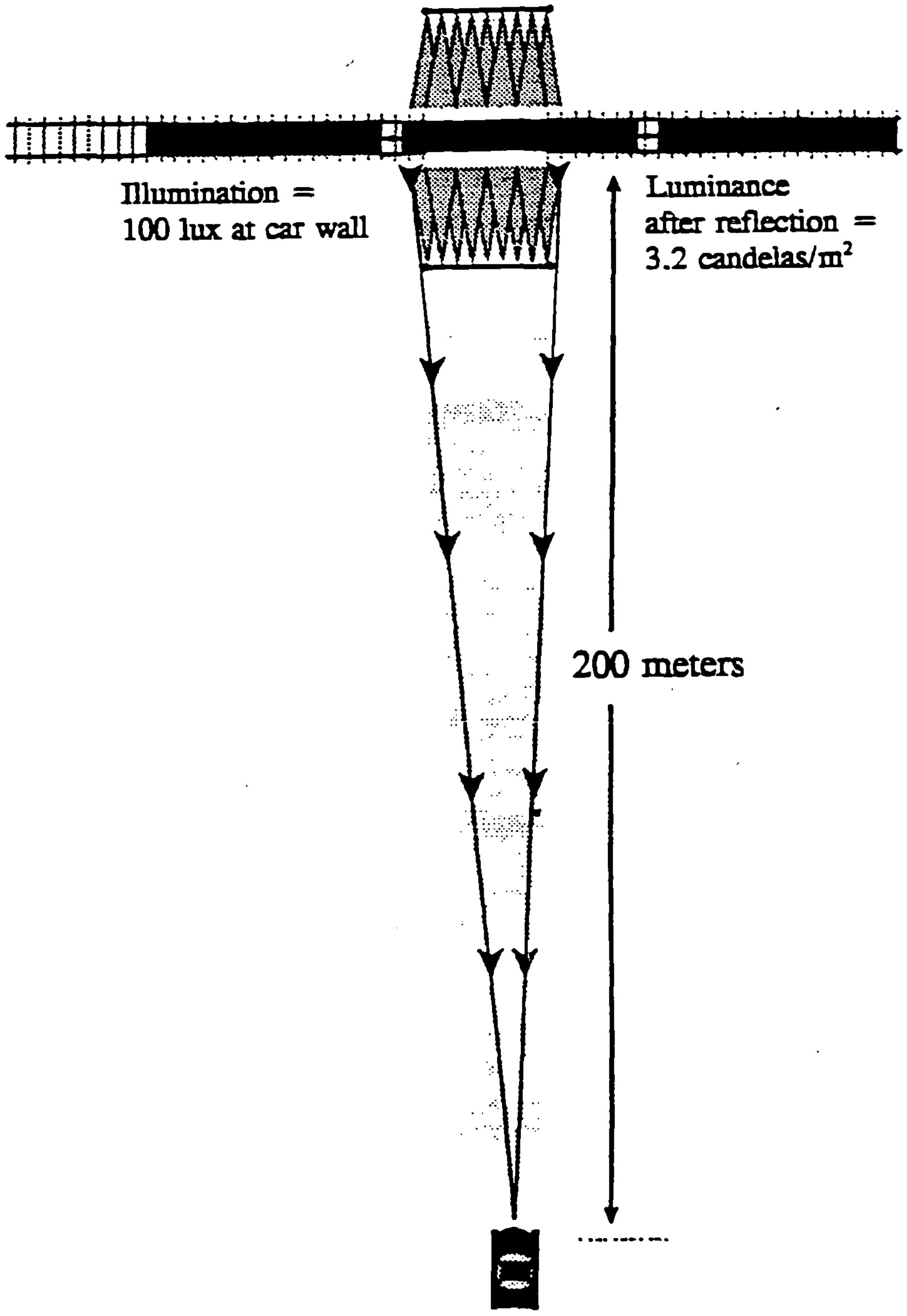

Figure 2. Initial Detection of Train in Crossing

5. GRADE CROSSING ILLUMINATION GUIDELINES

> Railroad grade crossings require illumination to identify the crossing, irregularities in the pavement surface, the presence or absence of a train in or approaching the crossing, and to allow recognition of unlighted objects or vehicles at or near the railroad crossing. The illumination should permit the recognition of signs and markings identifying the crossing.[11]

This continues to be the set of requirements for illumination at railroad grade crossings. The requirements can be divided into two distinct types: 1) illumination of the train in the crossing such that it can be recognized at a safe stopping distance, and 2) illumination of the crossing surface area and its surroundings, including signs and personnel, for the purpose of alerting the motorist to the presence of the crossing and making the crossing area and its surroundings visible to the motorist. In this section these requirements are discussed and guidelines are offered for achieving them, based on the recommendations and observations of Sections 1-4.

5.1 REQUIREMENTS FOR ILLUMINATION OF TRAIN

In the case of illumination of the vertical wall of a railroad car (Requirement 1.) both the amount of illumination required to recognize a train in the crossing and the need to minimize glare to the motorists on the other side of the track and to the train operator, from the illuminating source, must be considered. This tradeoff has been addressed in Section 4. Reduction of glare can

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[11] This comment on illumination requirements is taken from the standards document, ANSI/IES R-8, *American National Standard Practice for Roadway Lighting of 1983*.

be achieved by mounting the lights on towers horizontally offset from the crossing and using cutoff luminaires to permit illumination of the crossing without sending light down the highway or the track.

It is shown in Appendix A that a train with poorly reflecting walls can be detected with a probability of almost 100% if the train is illuminated with 100 lux and the car markings have a contrast equal to or exceeding 0.6. Although it is shown in Appendix C that 100 lux can be provided with present equipment, luminaires designed for this function only could effect a much higher illuminance. A conservative approach to the guidelines would be to require at least 100 lux.

The need to illuminate a vertical surface with spatially uniform, high intensity, suggests the use of several lamps in several luminaires, each lighting a different section of the surface. Several smaller physical size lamps, each of which covers a small solid angle, can be aimed to provide a prescribed light intensity distribution on a given aperture. Although engineering design is necessary to provide combinations of lamps and luminaires for this purpose, the costs of additional design are modest with respect to the cost of illumination equipment needed. It is shown in Appendix C that presently available equipment can be used to adequately light the train walls with minimum glare. Equipment consisting of many luminaires with lower power, however, can achieve a more uniform and efficient illumination of the aperture and permit the use of higher mountings for the luminaires. This will further reduce glare for the motorist and train operator.

Although it is convenient to light a vertical wall of the crossing by luminaires mounted on a pole, offset from the track and highway, a string of spot lights mounted on a cable, suspended by poles offset on each side of the roadway provides more efficient and more uniform lighting than pole-mounted luminaires. Since all the lamps and luminaires in such an installation are identical, this further simplifies the lighting design and obviates the need for a variety of equipment. The use of catenary-mounted lighting is thus recommended and suggested designs have been included.

The illumination of crossbucks is accomplished by the same luminaires that illuminate the train walls, the position of the crossbucks being less than 15 ft from track. This can be seen in the calculated illumination coverages of Appendix C.

5.2 REQUIREMENTS FOR ILLUMINATION OF CROSSING SURFACE

Illumination of the crossing surface is not the principal goal of crossing illumination; it is the illumination of the train itself that is the primary goal. The Illuminating Engineering Society recommends that the surface at the crossing be illuminated with 8.6 lux (0.8 footcandle)[12] over an area 100 ft along the roadway and 50 ft in excess of the roadway width.[13] This surface illumination falls within the range of that used for highway illumination and thus can be achieved by using standard highway lighting fixtures.

Luminaires for roadway lighting employ gaseous discharge lamps (mercury vapor, sodium vapor, etc.) which generate light over an extended volume. They are disposed to generate light beams occupying large solid angles and are thus suitable for the wide angle coverage needed to illuminate roadways.

The function of surface lighting is not very different from that of highway lighting in that it permits the motorist to monitor the road and grade-crossing surface quality for safe passage and to recognize potentially dangerous areas (in this case, the crossing

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[12] *IES Lighting Handbook*, pages 14-21, 1987.

[13] *Railroad-Highway Grade Crossing Handbook*, page 141, 1986.

itself). If the crossing occurs on an unlighted roadway, the above 200 ft x 75 ft lighted patch designated in the first paragraph of Section 5.2 will not only allow the road surface and crossing to be examined, it will serve as an identifier of the crossing as a potential danger. The short extent of the IES recommended surface lighting will make it useful only to slow traffic since it is a significant scene to the motorist only when she or he is within the patch or very close to it, the exceptions being at crossings with inclined terrain or trees and shrubbery. To be effective as a warning device the patch must be extended to the 60 mph stopping distance of 200 m. Part of the illumination of the patch will come from the light sources used to illuminate the train. Additional sources are needed to extend illumination to the whole patch.

5.3 GUIDELINES FOR THE ILLUMINATION OF TRAINS

It is shown in Appendix C that presently available equipment suitable for a modestly priced installation can provide a 100 lux illuminance on a train wall. One of the guidelines therefore, is that the illumination of the vertical wall of a railroad car at a grade crossing should exceed 100 lux (9.3 footcandles), with the ratio of average to minimum illumination not to exceed 2.0. (An illuminance meter oriented with its measuring face parallel to the absent car wall measures this illuminance.) Glare may be measured at the 200 m highway positions and at train operator positions along one signal block on either side of the crossing. The second guideline is the glare contrast factor GCF (see page A-7), at these positions should exceed 80%. Keep in mind that the optical task for the motorist is the luminance of the train wall, while the task of the train operator is the luminance of the track signals. Recommendations of the FHWA Railroad-Highway Grade

Crossing Handbook, FHWA-TS-86-215, Sept 86, page 141, are generally applicable as stated below:

> On uncurbed roadways, luminaire supports should be erected as far as practical from the traveled way. Luminaires should also be located to ensure damaged poles will not fall on the tracks. A distance of 25 to 50 feet from the nearest track is recommended. Mounting height should be in the range of 30 ft to 40 ft. The luminaires should be oriented toward the railroad. Ideally, luminaires should illuminate an area along the track that is 50% longer than the width of the road. Illumination should extend to approximately 15 ft above the top of rail.

The common and most efficient method of lighting a vertical wall is by spot lighting. A collection of spotlights, each illuminating a small area can be aimed so as to provide a very uniformly lighted plane. A luminaire composed of a bank of spot lights, collocated on the poles carrying the luminaires for horizontal lighting, can provide a 100 lux (9.3 footcandles) illumination on the vertical walls of a passing train (see Figure 4).[14] In Figure 5 an alternate configuration is shown using catenary supports which provides more uniform lighting. At this time the statistics of the reflecting and contrast properties of operating railroad cars are not known.

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[14] The principle applied here is to require the maximum illumination available with existing technology, subject to the glare contrast factor being greater than 0.8.

Average properties have been estimated thus permitting illuminance levels summarized in Table 1.[15]

TABLE 1. CROSSING ILLUMINATION GUIDELINES FOR TRAIN WALL

COVERAGE	ILLUMINATION OF VERTICAL WALL OF VIRTUAL RAILROAD CAR
150% width of highway, 15 ft above track	100 lux

5.4 GUIDELINES FOR ILLUMINATION OF CROSSING SURFACE

The recommendation for illumination of a *horizontal grade crossing surface* is that standard roadway lighting fixtures mounted on standard 30 ft poles be placed on opposite sides of the crossing. Low pressure sodium lights are recommended for this function, their color serving to identify the area as a grade crossing. The average illuminance levels over the crossing area, which includes the roadway for 200 meters on each side of the crossing, should be 8.6 lux (0.8 footcandles) with the ratio of maximum to minimum illuminance not to exceed 4.0 (this is consistent with highway illumination standards). The luminance of the track area depends not only on the illumination furnished by the luminaires, but on the scattering properties of the ballast, ties and rails and highway surface and will vary depending on the condition of these elements.

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[15] In establishing the illuminance guidelines of Table 1 consideration has been given to the work of Richard Mather of the Oregon PUC and William Hughes of the Portland, OR Bureau of Traffic Management, for the ANSI Committee on Roadway Lighting. The Oregon illuminance standards, the published papers of Richard Mather [5,6] and the referred papers of Bennett, Konz and Russel have been used for source material.

The glare contrast factor as measured at a position on the roadway 200 meters from the crossing and as measured along the track within one signal block on each side of the crossing should exceed 80%. The sources of glare are both those that illuminate the train walls and those that illuminate the crossing surface.

Two standard luminaires furnishing 20,000 lumens can light a 10,000 ft^2 surface to cover the crossing area (as shown in Figure 3). Additional luminaires can be placed to provide extended coverage. (See Table 2.)

TABLE 2. CROSSING ILLUMINATION GUIDELINES FOR CROSSING SURFACE

COVERAGE	ILLUMINANCE OF HORIZONTAL SURFACE (TRACK, BALLAST, HIGHWAY)
Grade crossing area, all signs, 200 m along highway on each side of crossing.	8.6 lux
The glare contrast factor along the track ± 1 signal blocks from the crossing must be greater than 0.8. Both horizontal and vertical sources contribute to glare, the optical task of the train operator is the luminance of track signals. The glare contrast factor at a point on the road 200 m from the crossing must be greater than 0.8. Both horizontal and vertical sources contribute to glare, the optical task of the motorist is the luminance of train wall (3 cd/m^2).	
To reduce glare, the previously cited rules are recommended: 1. Place lighting in offset position mounted on towers and aim the lights to direct minimum radiation along the highway and along the track. 2. Use fast angular falloff luminaires. 3. If there are more than two tracks, illuminate in depth by successive banks of lights, each close to the illuminated track so that luminaires need not be aimed toward the motorist.	

6. COMPLIANCE AND VERIFICATION

To assure that the illuminance at the train walls complies with the recommended guidelines, measurements should be made at the points of a vertical geometric grid extending across the roadway at the crossing occupying the plane of the nearest wall of a virtual train on each track, 15 ft high. The grid should consist of ten foot square cells. Across a 50 ft roadway the illuminance at the plane of the train wall as measured by a standard photometer should not fall below 100 lux at some standard position in each grid cell.

The glare contrast factor employing the estimated 3 cd/m^2 optical task luminance of the train wall[16] should not be less than 0.8 at the 200 m roadway position.

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[16] For a lambert scattering surface with a reflection of 10%, illuminated with 100 lux.

One 20,000 lumen lamp delivers 10 lux at crossing surface on 30 m x 30 m area.

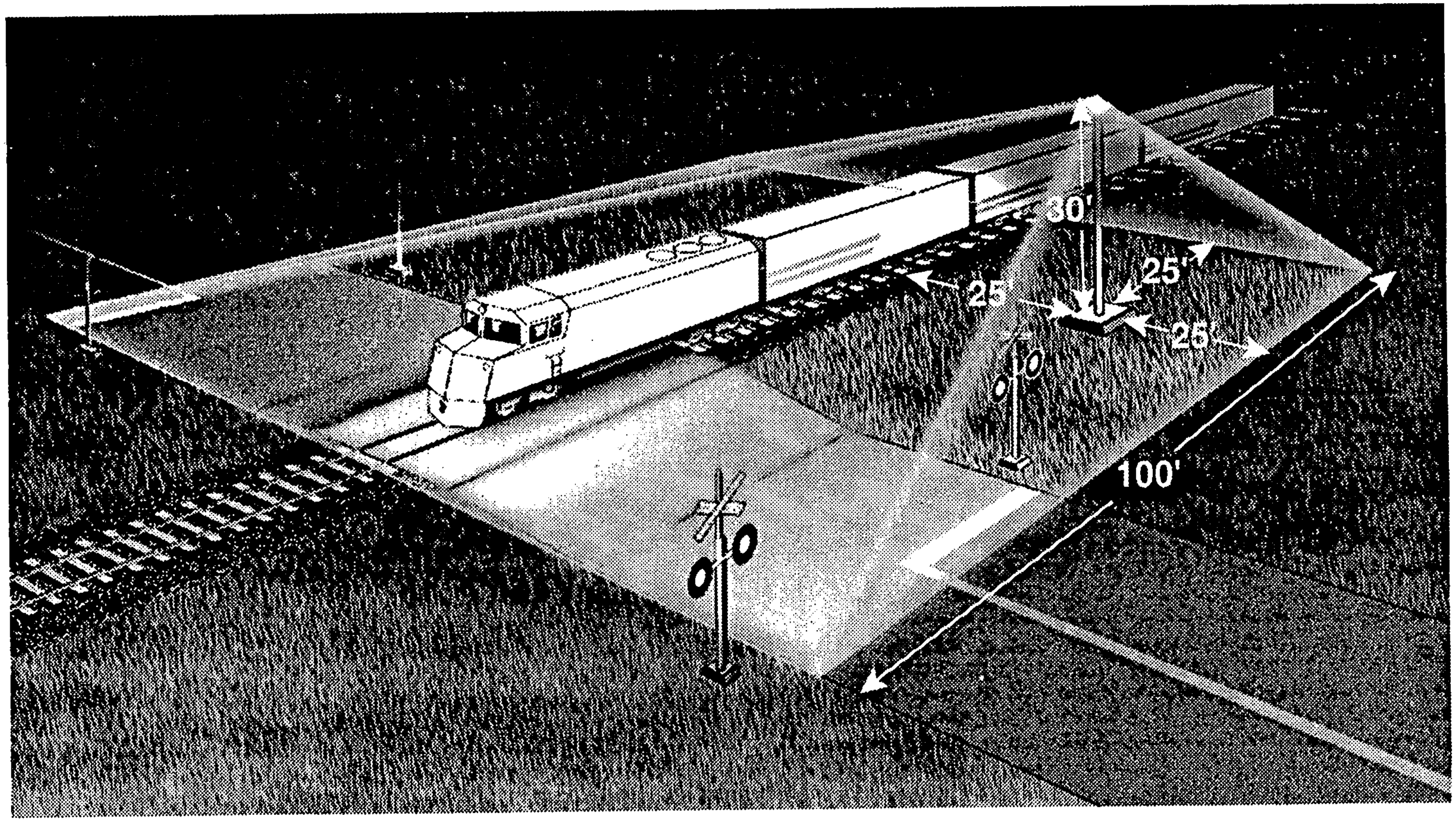
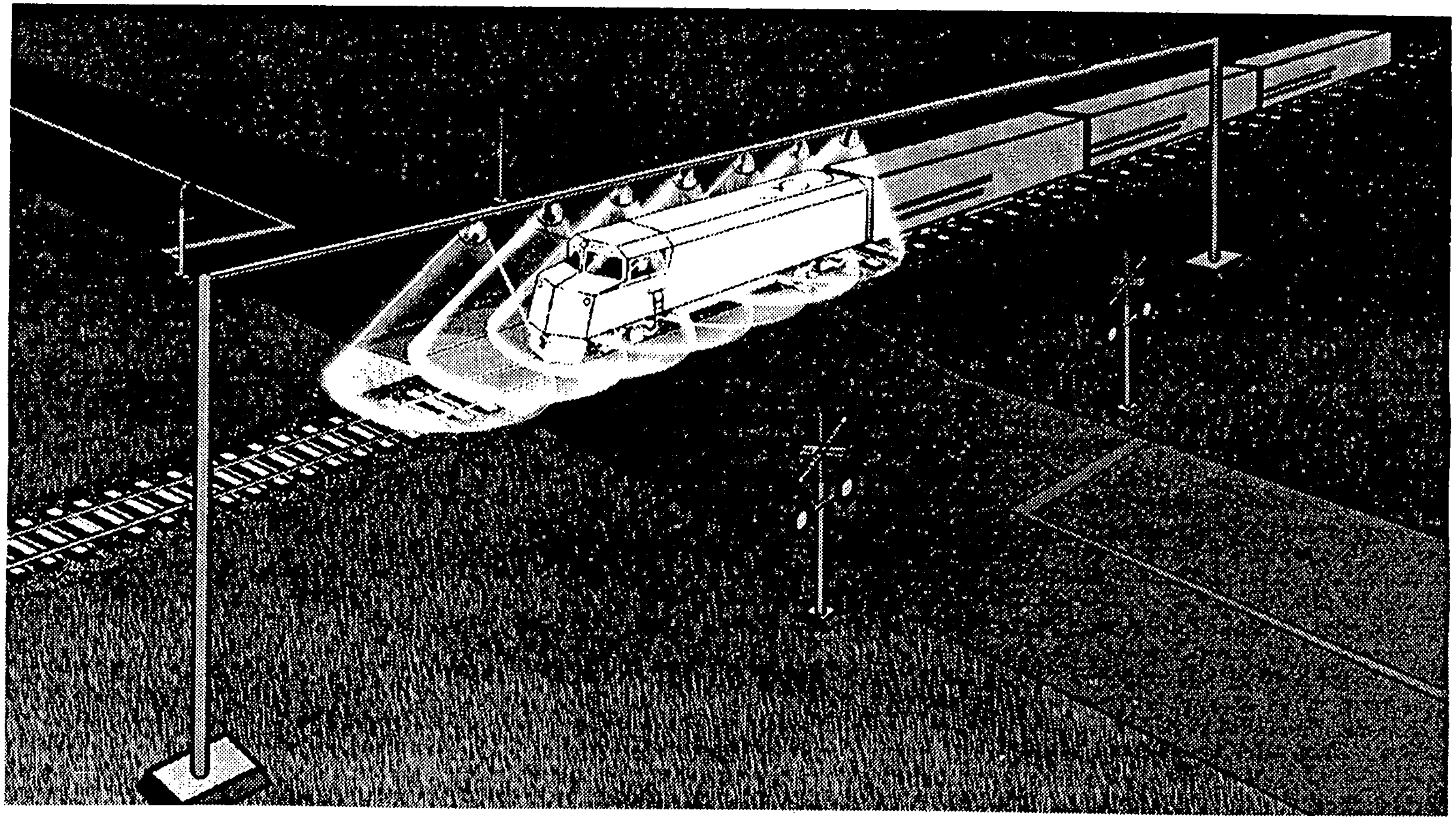


Figure 3. Illumination of Crossing Surface Area



Lamp array emits 10,000 lumens, delivers 200 lux at train wall

Figure 4. Illumination of Railroad Car Walls, Luminaires on Offset Poles

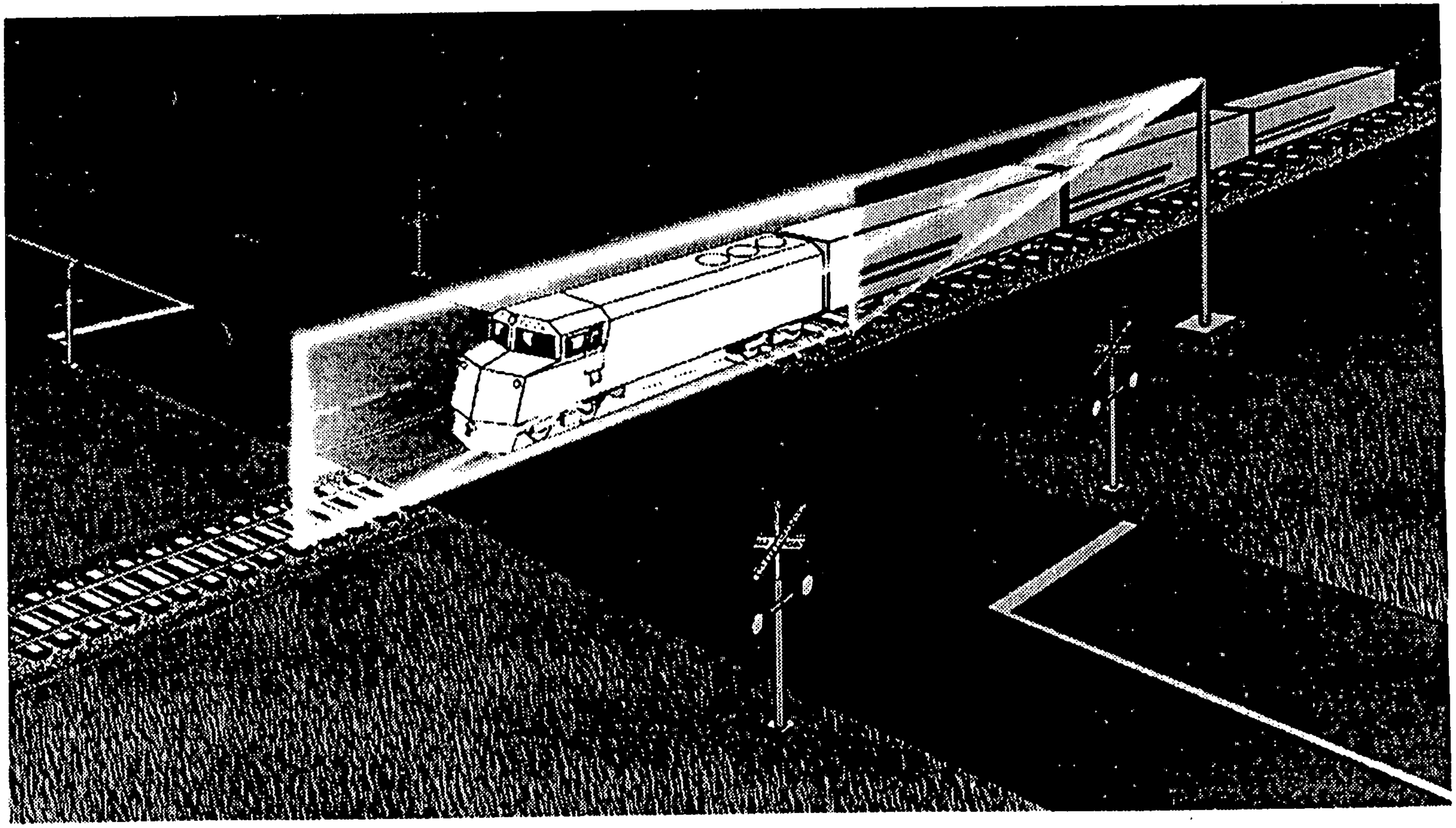


Figure 5. Illumination of Railroad Car Walls, Catenary Supports

The illuminance of the grade crossing surface area which extends across the roadway and 200 meters on each side of the tracks along the roadway, as measured by a standard photometer, should not fall below 8.6 lux.

The task luminances for the train operator must be measured and the glare luminance at the position of the operator within a signal block adjacent to the crossing must not be greater than 25% of the task luminance. The glare contrast factor will thus be 80% or greater.

7. ADDITIONAL REQUIREMENTS

It has been emphasized in the report that recommended guidelines are based on the results of classical detection experiments on optical tasks resembling the tasks of a motorist detecting a train under various conditions of illumination and available commercial lighting equipment. This is a well established method when direct experimental information is not available. The parameters which characterize the distribution of reflectivity of operating railroad cars constitute the biggest unknown in setting required illumination standards followed by the parameters which characterize crossing environments (vertical scattering objects).

Data on sidewall visibility could be obtained by illuminating the cars to the recommended 100 lux and measuring the luminance and contrast of the railroad cars at the sidewall, and visibility at the maximum required highway distance. Measurements would be made with standard optical instruments and corresponding responses of trained observers. The statistics of the detected optical signals will make it possible to modify or confirm our estimates of illuminance requirements and to establish standards of vertical illumination on a firm experimental basis. Along with these measurements, glare should also be measured with available instruments. Perceptions of glare which degrades vision should also be noted.

To insure that all isolated low traffic crossings without access to electrical power be illuminated, reliable low cost stored energy systems must be available. The stored energy sources, flood lights and switches described in Appendix B need to be developed with emphasis on reliability and low cost.

Manufacturers of lighting equipment should be commissioned to develop metal halide (or other) luminaires of suitable power and beam shape to be used in the recommended configurations to provide uniform lighting and efficient coverage for vertical illumination of train walls.

Illumination at crossings will require that equipment be available at a reasonable cost for acquisition, installation and maintenance.

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APPENDIX A VISUAL PERFORMANCE EXPERIMENTS AND CONCLUSIONS

Definitions:

1. Luminous flux:	Optical power measured in lumens. One lumen is defined as 1/683 watts of optical power at a frequency of 540 x 10^{12} hertz (555.185 nanometers)
2. Luminous intensity:	Optical power per unit solid angle emanating from a source, measured in lumens per steradian (candelas)
3. Illuminance:	Optical power per unit area falling on a surface in units of lumens per meter^2 (lux)
4. Luminance:	Optical power emitted from a surface in a given direction per unit solid angle, per unit of emitting surface, in units of lumens per steradian per meter^2 (candelas/m^2)
5. Luminance contrast:	Defined as the ratio of, the difference of the luminance of an object on a luminous background from the background luminance, to the background luminance.

The luminance of a surface which emits light, whether by reflection, scattering, or internal emission, is defined as the optical power radiated in a given direction per unit solid angle per unit surface area. It has dimensions of lumens per steradian per square meter (candelas per square meter).

Luminance contrast may be defined as: $C = \dfrac{L_d - L_b}{L_b}$

Where L_b = luminance of background

L_d = luminance of detail

Experiments in which the probability of detection of a simple test object on a uniform background is measured, have led to fundamental relationships between object detection and luminance of the background. Other experiments have been conducted which discovered fundamental relationships between recognition acuity (the ability to correctly identify a visual target, such as differentiating between a "G" and a "C") and retinal illuminance. Visual acuity, like detection, varies with the luminance and the time available for detection. A useful concept here is that of retinal illuminance since the function of the lens of the eye causes a surface of a given luminance to produce the same retinal illuminance at all distances of the eye from the surface.

The retina of the eye is sensitive to the illuminance of light falling on it, but flux density by itself does not determine the perception of brightness. It is the spatial variation of flux density (contrast) which determines this impression. A patch of retina with a background retinal illuminance may appear bright or dark depending upon the illuminance falling on adjacent areas.

In recent years the ambitious task of devising a method of using our understanding of the basic processes that govern visual performance to predict response behavior from a knowledge of stimulus parameters, was undertaken. The goal, of course, was to avoid having to study each task independently. Although this goal has not yet been achieved and human visual performance can be confidently predicted for only simple tasks under a restricted set of conditions, it is possible in many cases to make approximate predictions and to augment them with additional experiments.

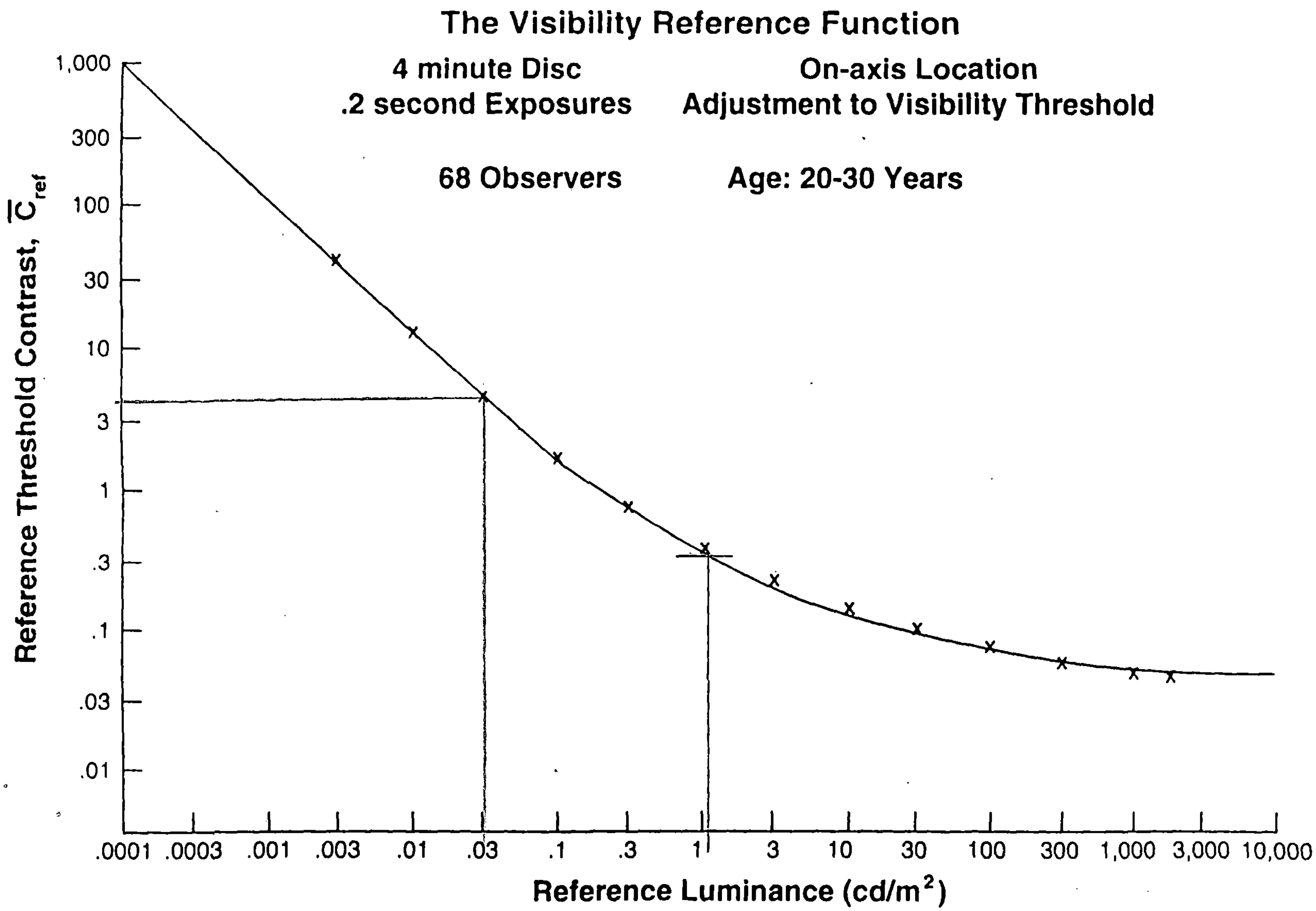

Figure A-1. The Visibility Reference Function (Reference 12.)

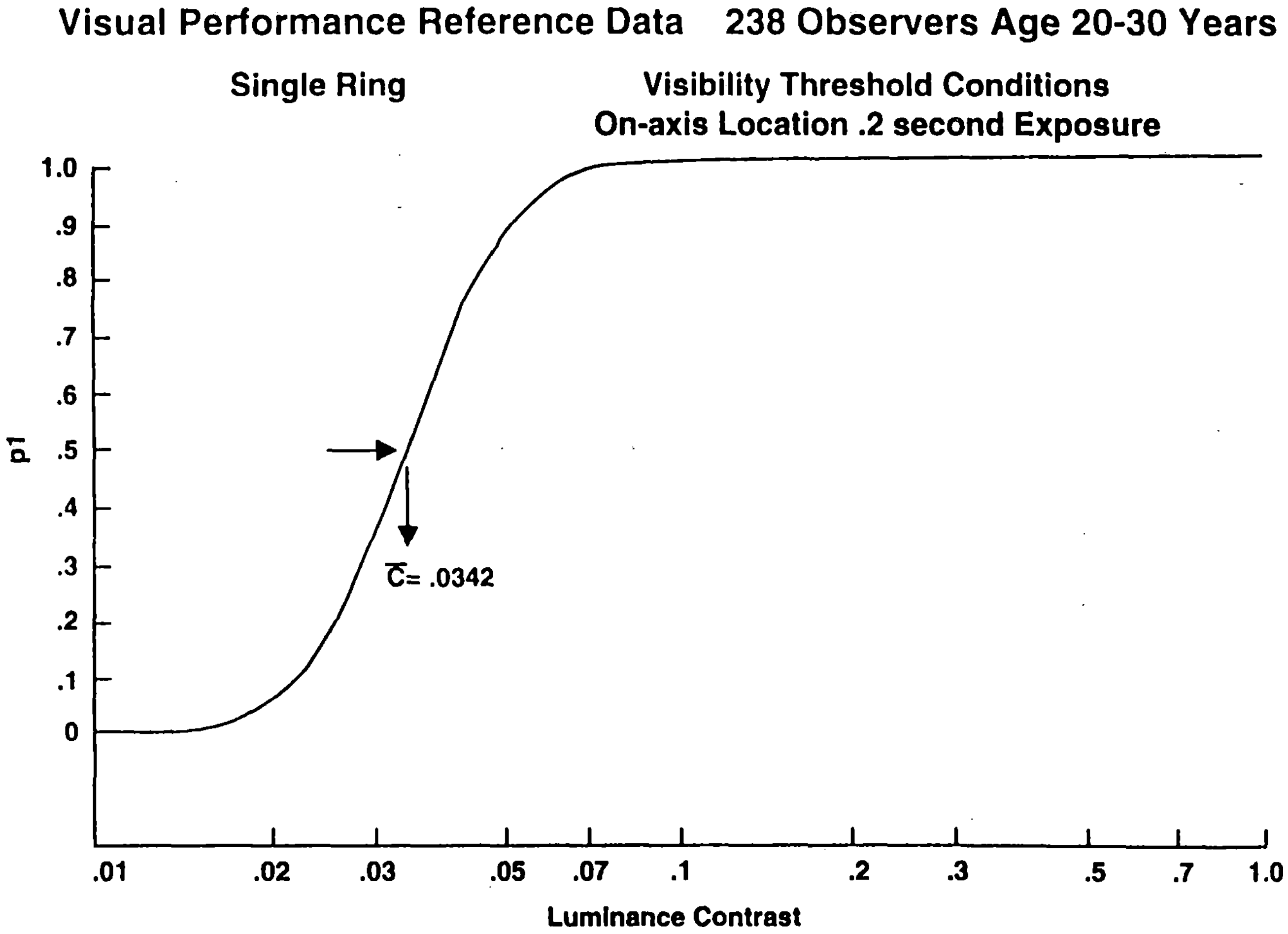

Figure A-2. The Visual Performance Curve

Figure A-1 is a graph of a fundamental relationship between object detection and the luminance of the background, it is called the Visibility Reference Function. It represents the task contrast required at different levels of task background luminance to achieve threshold visibility[17] for a 4-minute (angle) luminous disk exposed for 0.2 sec. The shape of the contrast threshold curve is relatively invariant for simple detection tasks in controlled environments. Furthermore, there is some evidence that the curve predicts visual performance for more complex functions such as the recognition of letters or words. Figure A-2 shows the relation of detection probability to contrast for the same optical task.

Illumination of a railroad car wall of 0.10 reflectivity and lambertian scattering characteristics (backscatters as if it were composed of randomly oriented reflectors), with 100 lux of in-place lighting would yield a background luminance of 3.2 candelas per square meter. From Figure A-1, a 0.5 probability of detection is predicted for a contrast of 0.3. Much higher contrasts can be expected on train walls which should lead to an almost 100% probability of detection (see Figure A-2). Combinations of such tasks (many characters, figures, luminance variations) increase the probability of detection).

The concept of the visual process, "disability glare" dates from a paper appearing in the 1927 JOSA by L.L. Holladay and another in the 1929 Proceedings of the Royal Society by W.S. Stiles.

Their work, carried out independently, found that off-axis lighted areas of the visual field reduce on-axis visual contrast sensitivity, operating as though a veil of equivalent luminance

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[17] Threshold visibility occurs when the illumination parameters permit an observer to detect an object in 50% of a set of decision attempts.

had been placed over the central visual field (commonly accepted as two degrees). Later work supported the idea that disability glare was caused by light scattered in the lens and cornea of the eye by this off-axis light. More recent studies[18] have resulted in the development of a quantitative measure of the effect:

$$L_v = K\sum_{\theta=1^\circ}^{90^\circ} \frac{L_s\cos(\theta)*\omega}{\theta(1.5+\theta)}$$

where L_v = equivalent veiling luminance (candelas/m^2).

L_s = luminance of an individual glare element of the task surround (candelas/m^2).

θ = angle between the glare element and the task (degrees).

ω = solid angle of an individual glare element.

K = disability glare constant, a proportionality parameter expressing the degree to which the eye of an individual observer produces scattered light per unit of glare element luminance. The recommended value of K is 10.0.

Both luminance at the task angle and observer age affect the value of K, with the glare constant increasing as either luminance is reduced or age is increased. A 65 year old driver is predicted to be described by a glare constant twice that of a 20 year old.

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[18] Reference 11.

The assessment of L_v in a night environment of interest requires the measurement of luminance and angular size of each elementary source of disability glare, followed by weighted summations to obtain the total glare effect. This is normally accomplished with the use of an optical attachment to a luminance photometer which performs the integration by means of an aspheric lens which is contoured to properly weight the off-angle light.

The media of the eye are not homogeneous but contain many inhomogeneities which scatter the incident light. A reduction in contrast is caused by the transfer of light which would go to the primary image, to other retinal areas, and vice versa. Because the reduction in contrast can be mimicked by adding a "veil" of luminance to the object, the effect is considered to be equivalent to *veiling luminance;* it is also called *disability glare.* The glare contrast factor which is a measure of the observer's ability to see an object in the presence of glare is defined as follows:

$$GCF = \frac{L}{L + L_v}$$

Where L = luminance of the task detail

L_v = spatially weighted average equivalent luminance

A GCF of 0.8 implies a reduction in contrast of 20 percent, the level below which adverse impairment occurs.

The factors affecting illumination requirements at a grade crossing have to do with the luminance contrast within the area of the train car body, and the luminance contrast of the car body against its background luminance (usually the sky). An illumination is required which greatly exceeds the threshold level for detection under ideal conditions of observer attention. The illumination should be such that the railroad car can be detected (recognized) at a super detection level as an obstacle for which braking and stopping the highway vehicle is mandatory.

For lambert scattering materials (where the luminance varies as the cosine of the departure from the normal angle), which pertains here, only the illuminance has significance. The physical condition of the average railroad car wall warrants the assumption that only lambertian scattering should be considered. It follows that the cars will be detected and recognized by a number of factors such as existing text and symbols on the cars, the moving silhouettes of the cars against the background luminance, and other contrasting features of the cars. The required illuminance will depend solely on the carbody contrast and background luminance. On a cloudy day the average illuminance of a vertical surface is 6,800 lux. To see the vertical surface of a train car at night it is not necessary to produce an illuminance of 6,800 lux, but enough illumination must be provided such that the reflectivity of the car will present an illuminance at the eye of the motorist (assuming lambert scattering) sufficiently above the detection threshold (to a certain extent the threshold is determined by the other light sources seen by the motorist) to provide a near 100% probability of detection. The ability to distinguish and identify the car is determined by the contrast of the car to its background and to the internal contrast of various areas of the car wall.

A driver approaches a railroad grade crossing, occupied by a train, at 97 km/h (60 mph) on a dry pavement. She or he requires a stopping distance of 200 m (660 ft) from the point where she or he first notices the train.[19] A line of spot lights located 8 meters from the track, at a height of 10 m, with reflectors to concentrate the light on the cars, can produce a 100 lux illuminance on the train car wall. Assuming a reflectance of 10% at the car wall the luminance (brightness) of the wall will be 3.2 candelas/m^2. The illuminance produced at the retina of the eye by its own lens is

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[19] Federal Highway Administration. 1986. *Railroad-Highway Grade Crossing Handbook.*

Flux = $\frac{\text{Lumen}}{m2}$

Luminance = lux x reflectance

.10 x 100 = 10 ≠ 3.2

determined only by the luminance of the wall and is independent of the distance of the wall to the observer. The train car forms a 4.3 degree wide image at the eye of the motorist 200 m removed from the car and a 30 cm letter or other spatial modulation on the car wall subtends an angle of five minutes of arc (one minute is resolvable by the human eye). The 100 lux illuminance should produce a near 100% detection probability[20] for an average background luminance of 3.2 candelas/m^2, but identification depends on the carbody contrast, the contrast of the car markings and the car wall.

The luminous intensity of the high beam headlights on an automobile is 150,000 candelas (lumens/steradian).[21] At 200 m, a vertical wall would have an illuminance of 3.7 lux. The illuminance guideline of 100 lux for in-place lighting, then, exceeds by a factor of 27 the illuminance provided by automobile headlights under ideal conditions. In many cases the train is illuminated by the low beam headlights which provide, under ideal conditions, 1/270 of that provided by the in-place lighting.[22] Calculation of the glare contrast factor (GCF) for a sample system such as in Figure 1 shows it to exceed 80% at the driver's position, 200 meters from the crossing, which should not affect driver visibility. A GCF of 80% or less is expected to produce adverse impairment of visibility.[23]

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[20] Reference 10.

[21] Reference 1., page 16-2.

[22] Reference 13.

[23] Reference 11.

APPENDIX B - SOLAR PANEL ILLUMINATION SYSTEM

STORED ENERGY SOURCES FOR ILLUMINATION

The stored energy source for illuminating a grade crossing for which local commercial power is not available may consist of either storage batteries charged by a solar panel or by an internal combustion engine running on either gasoline or natural gas. At the present time storage cells which convert liquid fuel directly to electrical energy are too costly for consideration. Rather than provide continuous illumination at night, it seems that such a system should be switched on by the passing train so as to conserve energy and equipment.

Such a system employing solar cells and storage batteries was installed near Longmont, Colorado in November 1990 at the Burlington Northern Denver Division. Burlington Northern has collaborated with Photocomm, Inc. to develop this system.
Figure B-1 describes the system. The experimental system consisted of the following main subsystems:

- o Photovoltaic modules and charge controllers
- o Maintenance-free lead acid batteries
- o Eight 50-watt quartz halogen flood lamps mounted on wooden poles
- o Telescopic switches and relay control system.

The telescopic switch consists of a telescope, a light sensing device and electronic circuitry which closes a relay upon the detection of the light from the train headlight. The relay activates a timer which runs the system for a preset period of time. If another train is detected during this period, the timer resets. Quartz halogen lights are used because they do not require any warm up. The telescopic switches are aimed down the track to provide about 30 seconds to a minute of system activation prior to the train arriving at the crossing.

The crossing has two 30-foot poles. The two telescopic switches are mounted on the master pole with a master controller. Each pole has four 50-watt flood light units, solar panels, and a battery enclosure mounted on it. The master pole has an additional equipment box mounted on it to house the monitoring equipment. An interconnect cable from the master pole to the remote pole activates the remote pole lights. The floodlights on each pole are positioned so that the roadway approach to the crossing and the side of the train are illuminated.

The solar panels charge a 24-volt bank of batteries on each pole. The system is sized to provide two hours of continuous operation. On this line there are usually six trains per night, requiring an activation time of 60 minutes per night.

This is a fairly rudimentary system. It functions reliably but it is clear that it could have a more flexible operation if an energy system using fossil fuel (oil or compressed gas) was employed to charge storage batteries for illumination and monitoring. The package would include a detection system consisting of a small train radio transmitter and wayside detector, and a logic system which could determine when the train had passed the crossing and if it came to a stop before the crossing or in the crossing.

BN solar powered crossing illumination system-site layout

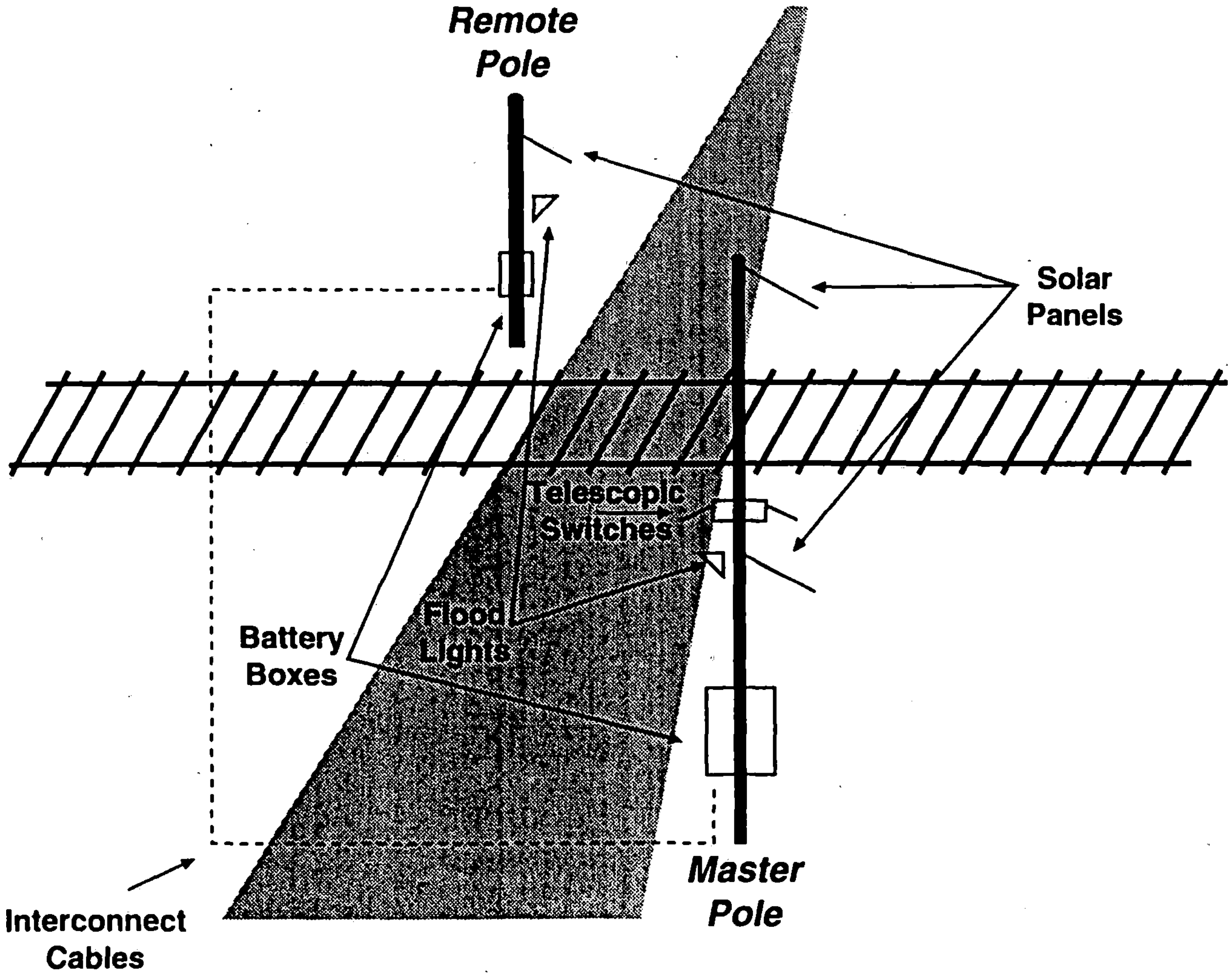

Figure B-1. Solar Powered Crossing Illumination System

APPENDIX C - ILLUMINATION DESIGNS

To further verify the performance of the designs recommended earlier in this report, the optical characteristics of three grade-crossing illumination designs have been calculated. The optical characteristics of presently available lamps and luminaires were used as input data to a computer program, Micro-Site-Lite, copyrighted by Lighting Sciences Inc. of Scottsdale, Arizona.

The results of the calculations showed that a two pole system, each pole containing two presently available luminaires with a single 400 watt metal halide lamp, can be used to illiminate the train wall. The luminaries appropriately aimed at the train, could illuminate a vertical plane, 15 ft high by 75 ft along the track, with more than 100 lux except for the four corners for which the illuminance would be 90 lux.

Repeating the calculation with 400 watt high-pressure sodium lamps gave a similar result except for the extreme right and left edges of the plane which at some points fell to 78 lux. The uniformity of the illumination on the vertical lighted plane is described as follows:

		METAL HALIDE	HIGH-PRESSURE SODIUM
AVERAGE ILLUM. (LUX)	=	281	212
MAXIMUM ILLUM. (LUX)	=	659	435
MINIMUM ILLUM. (LUX)	=	90	78
MAX./MIN. RATIO	=	7.3	5.6
AVG./MIN. RATIO	=	3.1	2.7

Calculations were made for catenary-mounted high-pressure sodium luminaires (rather than the spot lights described on page 14) which gave an illumination distribution very much like that produced by the pole-mounted lights. The average illumination in each of the three cases exceeded 250 lux. The use of additional luminaires or modification of the angular distribution of light emitted by the luminaires used in the calculations can provide the same average illumination in which the corners exceed 100 lux and the spatial variation of the aperture is smaller.

Description of Pole-Mounted Installation

The layout of equipment for the pole-mounted installation is shown in Figure C-1. In the figure a right-handed cartesian coordinate system is used in which the origin is 12.5 ft to the left of a 50 ft roadway, the x-axis is along the track, the z-axis is vertical and the y-axis is along the road. Two poles are located 25 ft from the edge of the roadway and 25 ft from the train face. Each pole contains two luminaires pointing at the train as shown. An identical system is located on the opposite side of the track also pointing at the train.

The pole-mounted luminaires are pointed at the train as follows:

List of Luminaire Positions and Aiming Directions

Lateral aiming angle of 0.0 degrees corresponds to the forward Y direction. Counterclockwise angles are negative, clockwise are positive. Vertical aiming angles are measured from the downward vertical to the aiming axis of the floodlight.

LUMINAIRE #			LOCATION-ft			AIMING ANGLE-degrees		AIMING POINT-ft		
POLE	#	TYPE	X	Y	Z	LAT	VERT	X	Y	Z
1	1	A	87.5	-25	25	292	72	25	0.0	3
1	2	A	87.5	-25	25	287	79	3	0.0	8.5
2	1	A	-12.5	-25	25	68	71.9	50	0.0	3
2	2	A	-12.5	-25	25	74	79.4	72	0.0	8.5

TOTAL NUMBER OF LUMINAIRES FOR ONE SIDE OF TRACK = 4

The luminaires are GE POWRSPOT 22 IN.
Each luminaire contains one 400 watt metal-halide lamp, MET 400.
Each luminaire has a 1.5 ft diameter emitting surface and emits 40K lumens with a light loss factor of 0.76.

The combination of the GE POWRSPOT 22 IN. luminaire with the metal halide lamp, MET 400 is a narrow beam light with a half-power width of 4°.

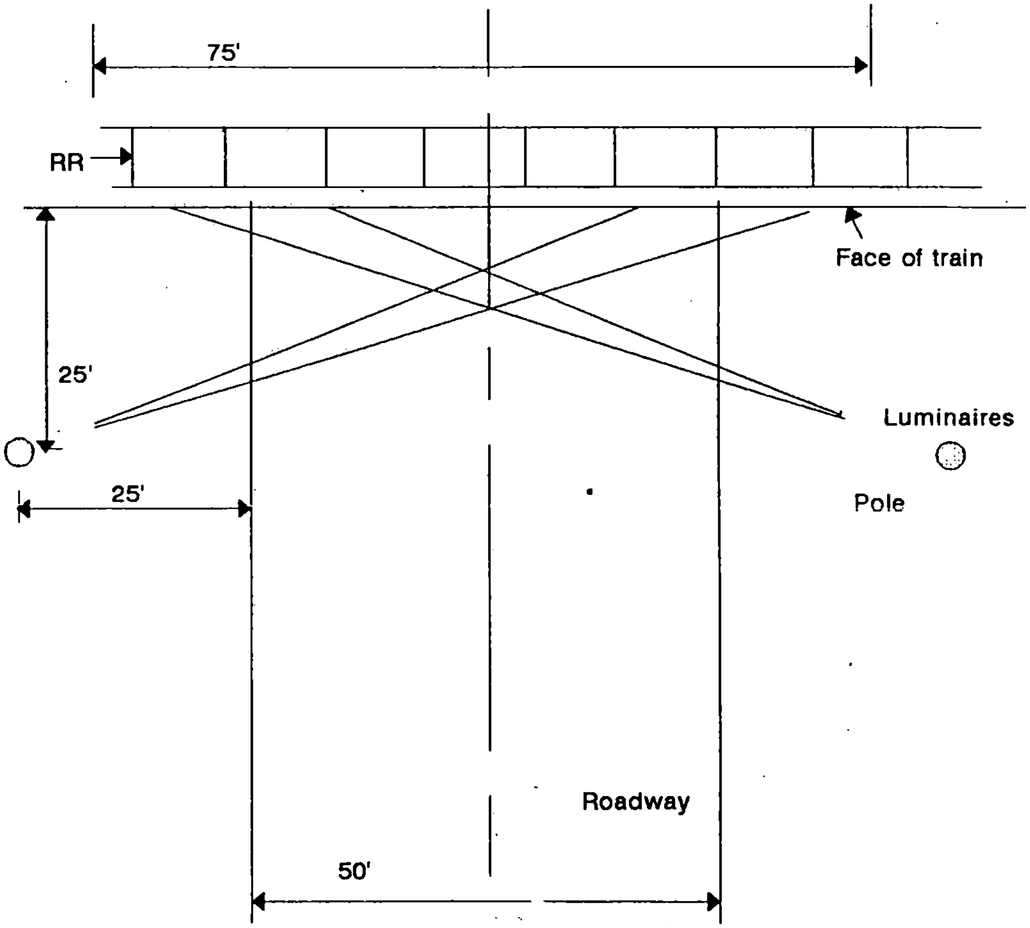

Figure C-1. Layout, Grade-Crossing Pole-mounted Luminaire Lighting

TABLE C-1. POLE-MOUNTED METAL-HALIDE GRADE-CROSSING ILLUMINATION

Vertical Illuminance Levels on Plane Y = 0, Values in Lux

Z COORD. FT											
15.0	91.3	145	175	163	179	192	179	163	175	145	91.3
12.0	172	272	278	253	285	317	285	253	278	272	172
9.0	301	384	279	250	440	471	440	260	279	384	301
6.0	256	229	221	388	659	584	659	388	221	229	256
3.0	139	154	249	612	538	333	538	612	249	154	139
0.0	90.3	133	258	405	240	129	248	405	258	133	90.3
	0.0	7.5	15.0	22.5	30.0	37.5	45.0	52.5	60.0	67.5	75.0

X COORDINATE FT

STATISTICS

AVERAGE LUX = 281
MAXIMUM ILLUM. (LUX) = 659
MINIMUM ILLUM. (LUX) = 90
MAX./MIN. RATIO = 7.3
AVG./MIN. RATIO = 3.1

TABLE C-2. POLE-MOUNTED HIGH-PRESSURE SODIUM Crossing Illumination

Vertical Illuminance Levels on Plane Y = 0, Values in Lux

Z COORD. FT											
15.0	78.3	124	205	336	410	424	410	336	205	124	78.3
12.0	84.3	137	216	343	428	435	428	343	216	137	84.3
9.0	89.3	134	192	311	395	399	395	311	194	134	89.3
6.0	84.3	130	176	259	329	331	329	259	176	130	84.3
3.0	84.9	123	167	206	248	255	248	206	167	123	84.9
0.0	84.6	116	143	158	178	189	178	158	143	116	84.6
	0.0	7.5	15.0	22.5	30.0	37.5	45.0	52.5	60.0	67.5	75.0

X COORDINATE FT

STATISTICS

AVERAGE LUX = 212
MAXIMUM ILLUM. (LUX) = 435
MINIMUM ILLUM. (LUX) = 78
MAX./MIN. RATIO = 5.6
AVG./MIN. RATIO = 2.7

The equipment layout which produced the vertical illuminance levels shown on this page is essentially the same as that shown in Figure **C-1** with only the lamps being changed. Here they are 400 watt high-pressure sodium lamps, HPS 400, which emit 50K lumens with a light loss factor of .86. The angular half-width of this equipment is the same as for the metal halide lamps, 4°.

Description of Catenary-Mounted Installation

The layout of equipment for the catenary-mounted installation is shown in Figure C-2. The coordinate system for this installation is identical to that described for the pole-mounted system of Figure C-1. Two poles are located 25 ft from the edge of the roadway and 25 ft from the train face. The luminaires are mounted on a cable or a bridge supported by the two poles. An identical system is located on the opposite side of the track also pointing at the train.

The luminaires are pointed at the train as follows:

List of Luminaire Positions and Aiming Directions

Lateral aiming angle of 0.0 degrees corresponds to the forward Y direction. Counter-clockwise angles are negative, clockwise are positive. Vertical aiming angles are measured from the downward vertical to the aiming axis of the floodlight.

LUMINAIRE #			LOCATION-ft			AIMING ANGLE-degrees		AIMING POINT-ft		
Posit	#	TYPE	X	Y	Z	LAT	VERT	X	Y	Z
1	1	A	7.0	-25	25	5	53	9	0.0	6
2	1	A	37.5	-25	25	0.0	53	38	0.0	6
3	1	A	68.0	-25	25	355	53	66	0.0	6

TOTAL NUMBER OF LUMINAIRES FOR ONE SIDE OF TRACK = 3

The luminaires are GE PF-400.
Each luminaire contains one 400 watt metal-halide lamp, MET 400.
Each luminaire has a 1.5 ft diameter emitting surface and emits 40K lumens with a light loss factor of .76.

This equipment has a half-power width of 45°.

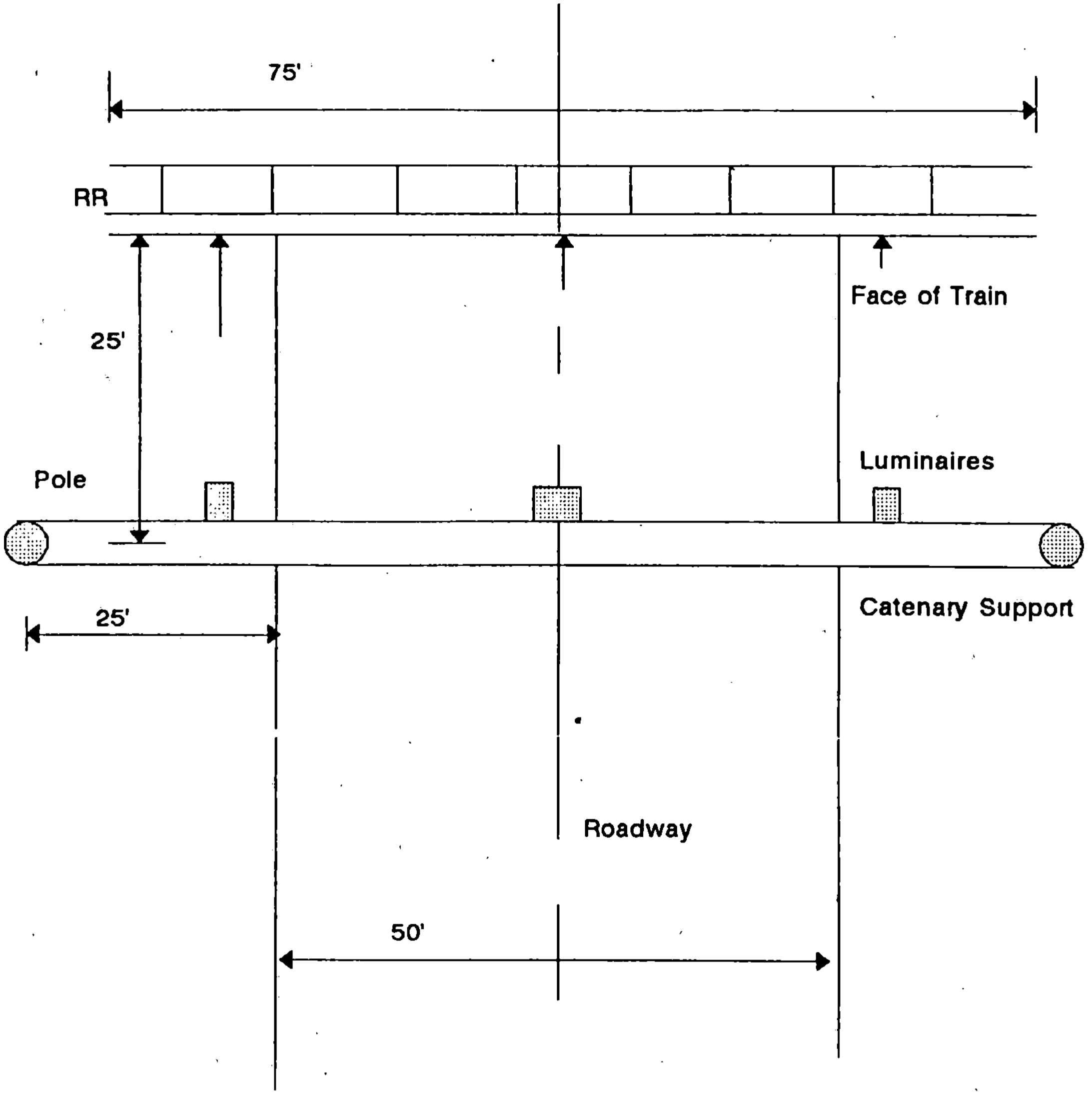

Figure C-2. Layout, Grade-Crossing Catenary-mounted Luminaire Lighting

TABLE C-3. CATENARY-MOUNTED METAL-HALIDE GRADE-CROSSING ILLUMINATION

Vertical Illuminance Levels on Plane Y = 0, Values in Lux

Z COORD. FT \ X COORDINATE FT	0.0	7.5	15.0	22.5	30.0	37.5	45.0	52.5	60.0	67.5	75.0
15.0	75.9	96.9	101	96.3	104	117	104	96.3	101	96.9	75.9
12.0	141	155	166	178	179	181	179	178	166	155	141
9.0	252	252	277	314	310	288	310	314	277	252	252
6.0	283	303	357	415	394	353	394	415	357	303	283
3.0	161	201	256	295	281	261	281	295	256	201	161
0.0	76.6	101	127	150	153	149	153	150	127	101	76.6

STATISTICS

AVERAGE LUX = 210

MAXIMUM ILLUM. (LUX) = 415

MINIMUM ILLUM. (LUX) = 76

MAX./MIN. RATIO = 5.5

AVG./MIN. RATIO = 2.8

The pole-mounted and catenary-mounted systems differ in their variations of intensity across a vertical plane at the track, but their statistics are similar. In each case the average/minimum is about 2.8 and the max/min is about 5.5. Note that the pole-mounted equipment used narrow beam lights (4°) while the catenary-mounted equipment used wide beam lights (45°).

The large variations in vertical illuminance can be attributed to the use of standard luminaires. More uniform illumination can be achieved if the luminaires are custom designed for the application.

Estimates made of the veiling luminance glare observed at the motorist's position and at the position of the train operator, when the luminaires are equipped with angular cutoffs, show that the glare will not limit the performance of motorist or train operator.

In all cases the task and veiling luminances must be measured at each site and modification of source placement made to satisfy the .25 rule.

In order to compute the glare contrast factor the luminance of the several tasks must be measured. The optical tasks of the motorist are detection of the luminance of the train, other automobile headlights and unlit objects (pedestrians). The optical tasks of the train operator are detection of the flashing window of the crossing lights, block signals in the vicinity of the crossing and lit, unlit and retroreflecting objects in the vicinity of the crossing. The veiling luminance of the illumination sources should be less than .25 times the task luminances.

A study of the costs of these designs yields the following information:

The cost of electric power for eight 400-watt luminaires is about $1,200./yr. The expected cost for equipment and installation, using wooden poles, is under $6,000.[24]

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[24] See reference 14.