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**Federal Railroad
Administration**

Safety of Highway-Railroad Grade Crossings

Use of Auxiliary External Alerting Devices to Improve Locomotive Conspicuity

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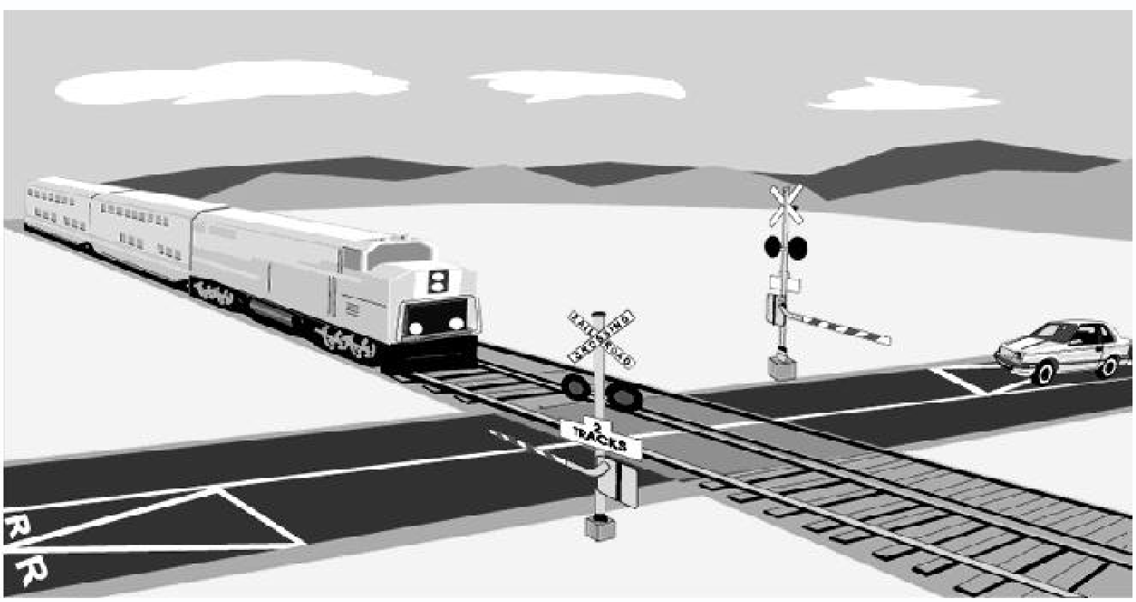

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13. ABSTRACT (Maximum 200 words)

Historically, highway-railroad grade crossings have represented a major hazard to motor vehicle drivers. The Federal Railroad Administration (FRA), U.S. Department of Transportation (USDOT) has initiated a comprehensive research program to address grade crossing safety issues in order to reduce the number of train-motor vehicle collisions. One area of study investigates measures to improve the ability of motor vehicle drivers to detect the approach of the train at grade crossings by enhancing train conspicuity.

The FRA has identified several types of auxiliary external alerting light arrangements as acceptable locomotive conspicuity measures and issued two Interim Rules in 1993 and 1994.

This study investigated the performance of currently available external visual alerting devices for installation on locomotives. A variety of passive (paint schemes and reflective materials) and active (lights) systems were reviewed. These devices were evaluated in terms of their ability to assist the motorist to: (1) detect the approaching train, (2) recognize the potential of the hazard, and (3) estimate its approach, and thus avoid a collision with a train at a grade crossing.

Controlled field testing was conducted to measure the effect of selected locomotive alerting light systems on observers. In-service railroad test operational experience for locomotives equipped with crossing lights, used in combination with the standard headlight, was also evaluated in terms of capital costs, maintenance, operational concerns, and accident data.

The results of the controlled field tests indicate that the use of selected alerting light systems, rather than use of the standard headlight alone, is an effective means of enhancing locomotive visibility. The preliminary in-service accident data provided by participating railroads indicates a potential for significant accident rate reduction with the use of the crossing light system.

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PREFACE

Historically, highway-railroad grade crossings have represented a major hazard to motor vehicle drivers. The Federal Railroad Administration (FRA), U.S. Department of Transportation (USDOT) has initiated a comprehensive research program to address grade crossing safety issues in order to reduce the number of train-motor vehicle collisions. One area of study concerns measures to improve the ability of motorists to detect the approach of the train at grade crossings by enhancing train conspicuity.

Early research concerning locomotive conspicuity was completed during the 1970s. Since then, alerting devices which enhance conspicuity have been improved and new devices have been invented. However, prior to the completion of this study, the impact of these devices on motorist behavior was not formally assessed, and the operational factors associated with the use of these alerting devices (e.g., costs, accident reduction potential) were not previously available or documented.

In support of the FRA, the John A. Volpe National Transportation Systems Center (Volpe Center) evaluated the performance of currently available auxiliary external alerting devices which may improve locomotive visibility at grade crossings. A variety of external visual alerting devices was reviewed and evaluated; these devices included various light systems, paint schemes, and reflective materials.

The overall results of the study indicate that the use of selected alerting light systems, rather than use of the standard headlight alone, can improve locomotive conspicuity, and suggest a potential for significant accident rate reduction with a minimum in capital costs, maintenance requirements, and operational concerns.

The FRA has been directed by law to develop a final rule for enhanced locomotive conspicuity. The results of the evaluation effort described in this report are intended to assist the FRA in the development of provisions for auxiliary external alerting light standards.

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This report was sponsored by the Federal Railroad Administration (FRA), U.S. Department of Transportation (USDOT) Office of Research and Development. The authors wish to thank William R. Paxton, Garold R. Thomas, and Thomas G. Raslear of that office for their direction and helpful guidance during the study of locomotive alerting lights documented in this report. In addition, Gordon Davids, Bruce F. George, and Grady C. Cothen of the FRA Office of Safety provided helpful input and review of the draft report.

The report was prepared by the staff of the John A. Volpe National Transportation Systems Center, USDOT Research and Special Programs Administration, (RSPA/Volpe Center). Volpe Center organizational units participating included the Accident Prevention Division and the Infrastructure Systems and Technology Division, Office of Systems Engineering; and the Operator Performance and Safety Analysis Division, Office of Research and Analysis.

Anya A. Carroll, Project Leader for the Volpe Center Highway- Railroad Grade Crossing Safety Research Program, provided overall direction. The Report Team Leader was Stephanie H. Markos, Volpe Center.

Jordan Multer, Volpe Center, directed the controlled field tests conducted at the Army Ammunition Facility in Ft. Eustis, VA. Other Volpe Center staff who contributed to the Ft. Eustis test effort include: Anthony T. Newfell, who provided technical creativity and logistics assistance; John K. Pollard and Andrew Kuan, who developed the data collection tools, including the hardware and software; and Robert M. DiSario and Peter H. Mengert, who provided expertise in reducing and interpreting the data following the completion of the data collection phase.

Floyd Bishop, John McGee, John Fairbanks, and George Hart of the Army Ammunition Facility, Ft. Eustis, VA, deserve special acknowledgment for their support in permitting use of their facilities, recruiting observers, and operating the locomotives during controlled field tests. Carol Pruesser, Robert Ulmer, and William Nissen provided valuable assistance in collecting the data and working with the observers.

John Fallowfield, CalTrain-Peninsula Corridor; James Grady, Consolidated Railroad Corporation (Conrail); and Michael Bishop and Daniel Gilbert, Norfolk Southern Railroad, each played a key role in the participation of their respective railroads during the conduct of the in-service operational evaluation of selected alerting light systems.

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Finally, Cassandra L. Oxley, EG&G Dynatrend, provided valuable suggestions to improve the clarity of language and overall readability of the text and prepared the report for final publication. Carolyn Cook and Daniel J. Morin, Camber Corporation, produced the majority of graphic illustrations contained in this report. Miche DuGren and Trevor May of Camber Corporation prepared the cover graphic illustration.

EXECUTIVE SUMMARY

BACKGROUND

Highway-railroad grade crossings represent a major hazard to motor vehicle drivers. According to Federal Railroad Administration (FRA) statistics, 4,661 accidents occurred in 1993, resulting in 554 fatalities and 1,769 injuries. Of the total accidents, 3,171 resulted from the train hitting the motor vehicle. Two potential causes for these accidents exist: the motorist either failed to see the train in time to avoid a collision or misjudged the time available to safely traverse the grade crossing. Alerting devices that enhance locomotive conspicuity (e.g., make it more noticeable and better attract the attention of the motorist) increase the likelihood that the motorist will see an approaching train in sufficient time to take appropriate collision-avoidance action at the grade crossing.

In 1992, the FRA was required by Congress to complete locomotive conspicuity research and to issue interim requirements which help alert motorists to an approaching train and thus reduce highway-railroad grade crossing accidents. The FRA identified several types of auxiliary external alerting light arrangements as acceptable locomotive conspicuity measures and issued two Interim Rules in 1993 and 1994. In support of the FRA effort, the Volpe National Transportation Systems Center (Volpe Center) investigated the performance of currently available external visual alerting devices for installation on locomotives. The results of the Volpe Center study are intended to assist the FRA in the development of final regulations for improving locomotive conspicuity.

STUDY OVERVIEW

The Volpe Center study evaluated a variety of external visual alerting devices including several light systems, paint schemes, and reflective materials.

In performing the study, a multifaceted research approach was employed that encompassed the following efforts:

- Identification and review of historical railroad locomotive alerting device use, related studies and current U.S. transportation agency alerting light requirements, and international locomotive alerting device requirements, to assess which may enhance the collision-avoidance behavior of motorists at grade crossings;

- Analysis and tests of various locomotive alerting light components to determine their ability to meet U.S. locomotive alerting light conspicuity requirements;

- Evaluation of controlled field tests to determine the effectiveness of selected auxiliary external locomotive alerting light systems in improving motorist ability to detect and estimate arrival time of locomotives; and

- Evaluation of railroad in-service operational tests to determine the capital costs, maintainability, operability, and accident reduction potential of selected locomotive auxiliary external alerting light systems.

SUMMARY OF FINDINGS

The Volpe Center reviewed and assessed a variety of active and passive external alerting devices which can enhance locomotive conspicuity.

Although passive alerting devices (e.g., paint schemes and reflective material) can be used to enhance locomotive conspicuity, their effectiveness in alerting a motorist to a train approaching a highway-railroad grade crossing is limited.

Accordingly, the major focus of the Volpe Center study was directed at evaluating locomotive alerting light systems.

Three types of experimental auxiliary external alerting light systems: (1) crossing, (2) ditch, and (3) strobe, were selected for controlled field tests; the standard headlight used alone served as a control. Crossing lights operate in a flashing mode, while ditch lights operate in a steady burn mode; focus angle may vary. Each type of experimental auxiliary alerting light system was operated in combination with the standard locomotive headlight. All of the alerting light systems were evaluated in terms of their effectiveness in improving the ability of the motorist to detect the approach of a train at a highway-railroad grade crossing and estimate its arrival time.

The results of the in-service railroad test operational experience for locomotives equipped with crossing light systems, used in combination with the standard headlight, were also evaluated in terms of capital costs, maintenance requirements, operational concerns, and potential accident reduction.

The overall findings of the study are summarized in Table E-1 and expressed as the relative ranking of the three selected auxiliary external alerting light systems (used in combination with the standard headlight) against a set of evaluation criteria; the standard locomotive headlight used alone was the baseline for ranking. The table provides a convenient means of integrating and presenting results of the study's multifaceted efforts. The evaluation criteria in Table E-1 were placed into three groups that reflect the primary source of the information used to establish the rankings: (1) Meets FRA Minimum Conspicuity Performance Requirements, (2) Controlled Field Tests, and (3) In-Service Test Operational Evaluation. Specific findings are further described in the topic items following Table E-1.

Table E-1. Study Findings - Relative Ranking of External Alerting Light Systems

ALERTING LIGHT SYSTEM	MEETS FRA MINIMUM CONSPICUITY PERFORMANCE REQUIREMENTS			CONTROLLED FIELD TESTS		IN-SERVICE TEST OPERATIONAL EVALUATION			
	Intensity	Flash Rate	Pattern Design	Detection	Estimation	Capital Costs	Maintenance Requirements	Operational Concerns	Accident Reduction Potential
Crossing Lights	1	1	1	2	2	-1	-1	-1	2
Ditch Lights	1	N/A	1	1	1	-1	0	-1	**
Strobe Lights	1	1	1	1	1	-1	-1	-1	1
Headlight Alone	0	N/A	0	0	0	0	0	0	0

Meets FRA Conspicuity Minimum Requirements

Intensity - ability of alerting light to meet FRA Interim Rule performance criteria for intensity

Flash rate - ability of alerting light to meet FRA Interim Rule performance criteria for flash rate

Pattern - ability of alerting light system to meet FRA Interim Rule design criteria for triangular pattern

Controlled Field Test

Detection - ability of alerting light system to improve detection of locomotive

Estimation - ability of alerting light system to improve estimation of locomotive arrival time at the grade crossing

In-Service Test Operational Evaluation

Capital Costs - equipment and installation costs

Maintenance Required - level of maintenance required

Operational Concerns - operational impacts

Accident Reduction Potential - observed potential to reduce accidents

The following is the description of the evaluation criteria numerical scores:

2 = Best; 1 = Better; 0 = Standard headlight baseline; -1 = Worse; -2 = Worst; ** = No supporting data

Meets FRA Minimum Conspicuity Requirements

This evaluation area includes three criteria: Intensity, Flash Rate, and Pattern Design. These evaluation criteria are based on minimum performance criteria as specified in the 1993 and 1994 FRA Interim Rules. Laboratory tests were conducted to measure intensity and flash rate performance, if applicable, for alerting light components. All of the alerting light systems identified in the FRA Interim Rules were also evaluated in terms of their ability to promote a distinctive triangular light pattern.

Intensity

All of the steady burn alerting light components tested and currently used by the industry exceed FRA requirements for intensity. However, only one strobe light tested meets the FRA minimum effective intensity requirements.

In addition, the alerting light intensities contained in the FRA Interim Rules are significantly higher than those of other U.S. transportation modes, as well as requirements specified in other international railroad transportation regulations. The vision of both motorists and engineers observing approaching trains could be impaired by the potential glare of high-intensity crossing and ditch alerting light systems.

Flash Rate

Neither the standard headlight (49 CFR, Part 225.125) nor the ditch light system (FRA Interim Rules) is intended to be operated in a flashing mode. These light systems were therefore rated as "Not Applicable." The crossing and strobe light systems were ranked as "Better" since both are capable of meeting the minimum flash rate requirements of the FRA Interim Rule criteria. The FRA Interim Rule criteria for strobe and crossing light flash rates are consistent with the Federal Aviation Administration (FAA) and U.S. Coast Guard (USCG) alerting light system requirements.

Pattern Design

The ability of an alerting light system to create a distinctive light pattern is important for enhancing motorist recognition of the approaching hazard as a train. This concept was adopted in the FRA 1994 Interim Rule and is considered in the design requirements for traffic control devices at highway intersections. The FRA pattern requirements are consistent with FAA and USCG alerting light regulations.

The use of a pair of crossing, ditch, or strobe lights, in combination with the standard headlight, meets the FRA triangular pattern specifications.

The use of either type of oscillating headlight, as described in the FRA Interim Rules, will not provide the FRA-specified triangular light pattern, unless used in combination with the crossing, ditch, or strobe light systems.

Controlled Field Tests

Controlled field tests of selected alerting light systems were conducted at Ft. Eustis, Virginia. Results of these tests were analyzed to measure observer (motorist) performance at a simulated 90^o highway-railroad grade crossing in two ways: (1) peripheral detection of each type of light, and (2) locomotive arrival time estimation. The crossing, ditch, and strobe light systems (operated in combination with the standard headlight) and the standard headlight used alone as a control, were tested. The three experimental auxiliary external light systems and the headlight, used alone, were evaluated under both daylight and darkness ambient light conditions. The results are expressed in terms of the ability of a stationary observer to detect and estimate locomotive arrival time at the simulated grade crossing.

The controlled field tests did not measure the potential effects of night vision impairment attributable to the alerting light systems. In addition, because the alerting light attributes differ (e.g., position above top of rail, focus angle from centerline of locomotive, type of lamp, and flash rate), it is unclear which of the specific attributes contributed to the effectiveness of the individual alerting light systems.

Train Detection

The results of this test indicate that all three selected auxiliary external alerting light systems increase the detectability of the locomotive when compared to the standard headlight alone.

The increase in detection distance provided by the crossing light system over that of the ditch and strobe light systems, and the standard headlight used alone, was statistically significant.

Estimation of Locomotive Arrival Time

Observer overestimation of train arrival at the simulated grade crossing was smaller for the three experimental auxiliary external alerting light systems than for the standard headlight alone, providing a greater safety margin.

Comparison of the arrival time judgments to a criterion of no errors in arrival time judgments indicated that the crossing light system provides the best overall performance over the range of time intervals investigated.

Railroad In-Service Test Operational Evaluation

The results of a railroad in-service test evaluation conducted to determine capital costs, maintenance requirements, operational concerns, as well as accident reduction potential are summarized below. CalTrain, Conrail, Norfolk Southern, and Burlington Northern participated to varying degrees in this evaluation.

Although ditch and strobe light systems were not used by the railroads participating in the evaluation, they are included in this discussion since they have been used by other railroads.

Capital Costs

The average capital (equipment and installation) costs of each of the auxiliary alerting light systems tested were estimated at approximately $2,600 per end of the locomotive. The costs include the installation of features to interconnect the operation of the alerting light system with activation of the audible warning device system, to limit locomotive engineer workload.

Maintenance Requirements

Maintenance information collected to date has been limited. Since the ditch light uses the same steady burn bulb as the standard headlight (and does not flash), it is expected to have a similar maintenance record. The flashing nature of the incandescent bulb component within the crossing light system may reduce bulb life expectancy unless the voltage is increased to allow the light to remain on, though it may appear to be off when in the flashing mode. Significant replacement of the crossing light incandescent bulb has not been documented to date, but crossing light systems have been ranked slightly lower than the standard headlight because of this uncertainty. The strobe light is not a standard replacement part and therefore has a lower ranking than the crossing or ditch light systems.

Operational Concerns

The issue of glare has been identified as a safety concern. The focus angles of auxiliary alerting lights aimed between 15° and 45° outward from the locomotive centerline may cause excessive glare to opposing train engineers and approaching motorists.

The train engineers of one railroad turn off the crossing light system when approaching opposing trains.

The standard headlight has a dimmer switch to compensate for brightness, whereas all applications of the auxiliary alerting light system must be completely turned off, either automatically (timed-out), or by the locomotive engineer.

Accident Reduction Potential

Accident data were obtained from three participating railroads for time periods prior to, during, and after crossing light system installation on their locomotives. Analysis of accident data provided by CalTrain and Norfolk Southern indicates a 76.4% and 54.6% accident reduction, respectively, after crossing light system installation; Conrail experienced a 74.3% accident reduction. Thus, for all three railroads, significant reductions in accident rates were observed for locomotives equipped with crossing light systems, compared to those equipped with the standard headlight alone.

These results, while positive, should be viewed with some caution since the data was too limited to provide a high level of statistical confidence. Other unaccounted for influences, such as educational and enforcement programs, may also have contributed to the accident reductions.

CONCLUSIONS

The results of the Volpe Center study indicate that selected auxiliary alerting light systems required by the FRA Interim Rules significantly improve locomotive conspicuity by providing additional information to assist motorists in: (1) detecting locomotives, (2) recognizing the train as a potential hazard, and (3) estimating train arrival time, thus reducing the potential for collisions at highway-railroad grade crossings.

The following specific conclusions are presented to the FRA for consideration in the final development of the final rule intended to improve locomotive conspicuity:

FRA Minimum Conspicuity Performance Requirements

- Auxiliary external alerting light systems are currently available which meet the FRA Interim Rule criteria for intensity and flash rate, if applicable.

- Train approach speed, sight distances, ambient light conditions, and glare should be considered when specifying minimum and maximum levels for alerting light luminous intensity and effective intensity.

- Crossing, ditch, or strobe light systems, used in combination with the standard headlight, provide a distinctive, uniform light pattern that can be recognized by motorists as signifying a locomotive.

- The use of either type of oscillating light, as described in the FRA Interim Rules, even if used in combination with the standard headlight, does not provide the FRA-specified triangular pattern.

Train Detectability and Arrival Time Estimation

- Each of the three experimental auxiliary external alerting light systems (crossing, ditch, and strobe), used in combination with the standard headlight, increases detectability of the locomotive over use of the standard headlight alone.

- Alerting light detection, under controlled field test conditions, was best with the crossing light system.

- Arrival time estimation, under controlled field test site conditions, was best with the crossing light system.

Capital Costs

- The average alerting light system capital costs (equipment and installation) are estimated to be

  $2,600 per end of locomotive.

Accident Reduction Potential

- In-service test accident data for three participating railroads show significant grade crossing accident reduction potential for locomotives equipped with the crossing light system, compared with those equipped with the standard headlight alone.

- The results of the in-service tests, while positive, should be viewed with some caution since the data was too limited to yield a high level of statistical confidence.

Other Considerations

- Passive alerting devices are considered to be of only limited effectiveness in improving locomotive conspicuity. Accordingly, locomotive passive alerting devices should be used only as a secondary technique to reduce collisions at highway-railroad grade crossings.

- Multiple lights, luminous and effective intensity, focus angle, spatial dimensions, and pattern all contribute to increasing the visual alerting signal provided to the motorist.

- An intensity control which supplies a lower luminous intensity level for the entire alerting light system, similar to the "dimmer" switch currently used for the standard headlight, would reduce the potential for glare.

- A "cross-eyed" alerting light beam pattern with lights angled inward and focused an extended distance down the track appears to have the positive features of a wider beam width and range in front of the train, as well as less potential for blinding motorists.

GLOSSARY

Candela (cd) - unit of luminous intensity produced by a point light source.

Candlepower - used as another term for candela.

Effective intensity - optical power output of a flashing light. The apparent luminous intensity of a flashing light as measured by the intensity of a steady white light is seen to be as equally bright when viewed at the same distance. (Expressed in units of "effective candela")

Footcandle (fc) - unit of illuminance equal to 1 lumen per square foot.

Footlambert (fL) - unit of luminance equal to $1/\pi$ candela per square foot.

Illuminance - optical power striking a surface per unit area.

Lumen - unit of optical power equal to 1/683 watts.

Luminance - luminous intensity per unit area reflected from or emitted by a surface.

Luminous intensity - optical power output of a point light source, per unit solid angle. (Expressed in units of "candela")

Lux - unit of illuminance equal to 1 lumen per square meter. One lux equals 0.093 footcandle.

Photometer - instrument used to measure photometric quantities such as illuminance, luminance, and luminous intensity.

TABLE OF CONTENTS

Section | Page

EXECUTIVE SUMMARY vii

1. INTRODUCTION 1-1

1.1 BACKGROUND 1-1
1.2 OBJECTIVE 1-3
1.3 APPROACH AND SCOPE 1-3

2. MOTOR VEHICLE DRIVER BEHAVIOR AND LOCOMOTIVE CONSPICUITY 2-1

2.1 MOTORIST DETECTION OF LOCOMOTIVE APPROACH TO HIGHWAY-RAILROAD GRADE CROSSINGS 2-1

2.1.1 Locomotive Visual Characteristics 2-2
2.1.2 Highway-Railroad Grade Crossing Configuration 2-2
2.1.3 Motorist Peripheral Vision 2-3

2.2 MOTORIST RECOGNITION OF TRAIN HAZARD 2-5
2.3 MOTORIST ESTIMATION OF TRAIN ARRIVAL TIME AT GRADE CROSSING 2-6
2.4 SUMMARY 2-8

3. LOCOMOTIVE VISUAL ALERTING DEVICES 3-1

3.1 ACTIVE AND PASSIVE ALERTING DEVICES 3-1

3.2 STANDARD HEADLIGHT 3-2

3.3 ACTIVE EXTERNAL ALERTING DEVICES - OVERVIEW 3-4

3.3.1 Oscillating Lights 3-4
3.3.2 Rotating Beacon Lights 3-5
3.3.3 Strobe Lights 3-5
3.3.4 Ground Lights 3-5
3.3.5 Ditch Lights 3-6
3.3.6 Crossing Lights 3-8

Section Page

3.4 INTERNATIONAL ALERTING DEVICES 3-9

3.4.1 International Union of Railways (UIC) 3-9
3.4.2 Great Britain 3-10
3.4.3 Australia 3-12

3.5 EXTERNAL ALERTING LIGHTS - ANALYSIS 3-13

3.5.1 Standard Headlights, Oscillating Lights, Rotating Beacon Lights, and Strobe Lights 3-14
3.5.2 Ditch Lights and Crossing Lights 3-16
3.5.3 Triangular Light Pattern 3-16

3.6 PASSIVE EXTERNAL AUXILIARY ALERTING DEVICES - REVIEW AND ANALYSIS 3-17

3.6.1 Paint Schemes 3-17
3.6.2 Reflective Materials 3-19

3.7 FINDINGS 3-20

3.7.1 Alerting Lights 3-20
3.7.2 Passive Devices 3-22

3.8 CONCLUSIONS 3-22

4. ALERTING LIGHT PERFORMANCE CONSIDERATIONS 4-1

4.1 PERFORMANCE CRITERIA 4-1

4.2 DOT ALERTING LIGHT PERFORMANCE REQUIREMENTS 4-2

4.2.1 "Aids to Navigation" Light Systems 4-3
4.2.2 "Anti-Collision" Light Systems 4-5
4.2.3 Analysis 4-8

4.3 ALERTING LIGHT COMPONENTS SELECTED FOR TESTS 4-11

4.3.1 Steady Burn Lights 4-11
4.3.2 Strobe Lights 4-13

4.4 ALERTING LIGHT COMPONENT LABORATORY TESTS 4-15

4.4.1 Background 4-15
4.4.2 Test Conduct 4-15

Section Page

4.5 ALERTING LIGHT COMPONENT TEST RESULTS 4-16

4.5.1 Steady Burn Lights 4-16
4.5.2 Strobe Lights 4-16

4.6 FINDINGS 4-17

4.7 CONCLUSIONS 4-19

5. CONTROLLED FIELD TESTS OF SELECTED ALERTING LIGHT SYSTEMS 5-1

5.1 METHODOLOGY 5-1

5.1.1 Field Test Site 5-2
5.1.2 Locomotives and Experimental Alerting Light Systems 5-3
5.1.3 Observers 5-3
5.1.4 Experimental Tasks 5-4
5.1.5 Experimental Variables 5-6

5.2 RESULTS 5-7

5.2.1 Detectability 5-7
5.2.2 Arrival Time Estimation 5-11

5.3 FINDINGS 5-16

5.3.1 Detectability 5-17
5.3.2 Arrival Time Estimation 5-19

5.4 CONCLUSIONS 5-19

5.4.1 Detectability 5-20
5.4.2 Arrival Time Estimation 5-20

6. RAILROAD IN-SERVICE TEST EVALUATION 6-1

6.1 RAILROAD IN-SERVICE TEST EVALUATION PROGRAM 6-1

6.2 CALTRAIN-PENINSULA CORRIDOR COMMUTER SERVICE 6-2

6.2.1 Alerting Light System 6-2
6.2.2 Equipment and Installation Costs 6-3

Section Page

6.2.3 Maintenance Requirements 6-4
6.2.4 Operational Concerns 6-5
6.2.5 Accident Data 6-6

6.3 CONSOLIDATED RAIL CORPORATION 6-8

6.3.1 Alerting Light System 6-9
6.3.2 Equipment and Installation Costs 6-11
6.3.3 Maintenance Requirements 6-11
6.3.4 Operational Concerns 6-11
6.3.5 Accident Data 6-11

6.4 NORFOLK SOUTHERN RAILROAD 6-13

6.4.1 Alerting Light System 6-13
6.4.2 Equipment and Installation Costs 6-16
6.4.3 Maintenance Requirements 6-16
6.4.4 Operational Concerns 6-16
6.4.5 Accident Data 6-16

6.5 BURLINGTON NORTHERN RAILROAD 6-19

6.5.1 Alerting Light System 6-19
6.5.2 Equipment and Installation Costs 6-20
6.5.3 Maintenance Requirements 6-20
6.5.4 Operational Concerns 6-20
6.5.5 Accident Data 6-20

6.6 FINDINGS 6-20

6.6.1 Capital Costs 6-20
6.6.2 Maintenance Requirements 6-21
6.6.3 Operational Concerns 6-21
6.6.4 Accident Reduction Potential 6-21

6.7 CONCLUSIONS 6-25

7. OVERALL FINDINGS AND CONCLUSIONS 7-1

7.1 SUMMARY OF FINDINGS 7-1

7.1.1 Meets FRA Minimum Conspicuity Requirements 7-3
7.1.2 Controlled Field Tests 7-4
7.1.3 In-Service Test Operational Evaluation 7-7

Section | Page

7.2 CONCLUSIONS 7-9

7.2.1 FRA Minimum Conspicuity Performance Requirements 7-10
7.2.2 Train Detectability and Arrival Time Estimation 7-10
7.2.3 Capital Costs 7-11
7.2.4 Accident Reduction Potential 7-11
7.2.5 Other Considerations. 7-11

8. REFERENCES 8-1

APPENDIX A - SUMMARY OF FRA INTERIM RULES FOR AUXILIARY EXTERNAL ALERTING LIGHT SYSTEMS A-1

APPENDIX B - GRADE CROSSING CONFIGURATION ANGLES B-1

APPENDIX C - ALERTING LIGHT COMPONENT ISO-INTENSITY CONTOUR PLOTS C-1

APPENDIX D - CONTROLLED FIELD TESTS-SUPPLEMENTARY INFORMATION. D-1

APPENDIX E - PEAK LIGHT INTENSITY AS A FUNCTION OF POWER SUPPLY VOLTAGE E-1

APPENDIX F - BIBLIOGRAPHY F-1

LIST OF FIGURES

Figure		Page
2-1	Peripheral Vision Range	2-3
2-2	Observation Angle as a Function of Distance from Grade Crossing	2-4
2-3	Triangular Locomotive Light Pattern	2-6
3-1	External Locomotive Alerting Devices (Lights and Reflective Material)	3-2
3-2	Standard Headlight Beam Width/Focus Angle	3-3
3-3	Ground Light Beam Focus Angle	3-6
3-4	"Canadian" Ditch Lights - Beam Focus Angle	3-7
3-5	U.S. Ditch Lights - Maximum/Minimum Beam Focus Angle	3-8
3-6	Crossing Lights - Maximum/Minimum Beam Focus Angle	3-9
3-7	UIC Locomotive Triangular Light Pattern (Germany)	3-10
3-8	Australian Alerting Light Beam Focus Angle	3-13
3-9	Locomotive Paint Schemes	3-18
4-1	200-Watt PAR 56 30 V Locomotive Headlight	4-12
4-2	12 V (DC) Circular Strobe Light	4-13
4-3	30 V (DC) 360° Strobe Light	4-14
4-4	30 V (DC) Rectangular Strobe Light	4-14
5-1	Field Test Site Layout and Observer Position	5-2
5-2	Ft. Eustis Locomotives Equipped with External Experimental Alerting Light Systems	5-3
5-3	Laptop Computer Visual Display (Arrows Shown Actual Size)	5-5
5-4	Effect of Alerting Light System on Mean Arrival Time by Estimated Time Interval	5-15
6-1	CalTrain Locomotive Equipped with Crossing Light System	6-4

LIST OF FIGURES (Continued)

Figure		Page
6-2	CalTrain Train Cab-Car Not Equipped with Crossing Light System	6-5
6-3	Conrail Locomotive Equipped with Crossing Light System	6-10
6-4	Norfolk Southern Locomotive Equipped with Crossing Light System	6-15
7-1	Effect of Alerting Light System on Mean Arrival Time by Estimated Time Interval	7-7

LIST OF TABLES

Table		Page
E-1	Study Findings - Relative Ranking of External Alerting Light Systems	ix
4-1	DOT Agency Performance Requirements for Alerting Light Systems	4-2
4-2	FRA Requirements for Locomotive "Anti-Collision" Light Systems	4-6
4-3	USCG Marine Vessel Maximum Luminous Intensity for Anti-Collision Light Systems - Steady Burn	4-8
4-4	Alerting Light Components Selected for Tests	4-11
4-5	Steady Burn Locomotive Headlight Data	4-16
4-6	Strobe Light Data	4-17
5-1	List of Independent Variables	5-7
5-2	Mean Detection Distance of Alerting Light System by Ambient Light Condition	5-9
5-3	Mean Detection Distance by Alerting Light System	5-10
5-4	Mean Arrival Time Judgment by Alerting Light System	5-13
5-5	Mean Arrival Time Judgment by Time Estimation Interval	5-14
5-6	T-Values for Alerting Light System by Time Interval	5-16
6-1	CalTrain Locomotives Equipped with Crossing Light System During Installation Time Period	6-3
6-2	CalTrain Accident Data	6-7

LIST OF TABLES (Continued)

Table		Page
6-3	Conrail Grade Crossing Accident Data	6-12
6-4	Norfolk Southern Grade Crossing Accident Data	6-18
6-5	Crossing Light System Accident Reductions - CalTrain and Norfolk Southern.	6-22
6-6	Crossing Light System Accident Reductions - Conrail	6-22
7-1	Study Findings - Relative Ranking of External Alerting Light Systems	7-2
7-2	Mean Detection Distance by Alerting Light System	7-5
7-3	Crossing Light System Accident Reductions - CalTrain and Norfolk Southern	7-9
7-4	Crossing Light System Accident Reductions - Conrail	7-10

1. INTRODUCTION

Highway-railroad grade crossings represent a major hazard to motor vehicle drivers. In 1993, 4,661 grade crossing accidents/incidents occurred which resulted in 554 fatalities and 1,769 injuries according to Federal Railroad Adminstration (FRA) statistics [1]. Of the total accidents, 3,171 resulted from the train hitting the motor vehicle. Two possible causes for these types of collisions exist: the motorist failed to see the train, or misjudged the time available to safely traverse the grade crossing. Alerting devices that enhance locomotive conspicuity (e.g., make it more noticeable and better attract the attention of the motorist) increase the likelihood that the motorist will see the approach of the train in sufficient time to take appropriate collision-avoidance action at the grade crossing.

The FRA requires that each locomotive be equipped with a standard headlight [2]. This light is designed to allow the train engineer to see down the track rather than make the locomotive more conspicuous to the motor vehicle driver. To increase train conspicuity, many railroads have equipped their locomotives with external auxiliary alerting devices such as strobe lights, ditch lights, crossing lights, oscillating devices, paint schemes, and reflective materials. However, previous operational experience with these alerting devices has been insufficient to evaluate their effectiveness in reducing the number of train-motor vehicle collisions.

In support of the FRA, the Volpe National Transportation Systems Center (Volpe Center) evaluated the effectiveness of currently available auxiliary external alerting devices that may improve locomotive conspicuity at grade crossings. This report describes the results of the Volpe Center evaluation.

1.1 BACKGROUND

The failure of the motor vehicle driver, under certain conditions, to detect the approach of a train at a highway-railroad grade crossing is a major factor in train-motor vehicle collisions. About two-thirds of U.S. public grade crossings are not equipped with active motorist warning devices such as flashing lights and gates. It is difficult for many motorists, particularly at night, to detect a moving train and correctly estimate its time of arrival at passive grade crossings. If the train is not detected before the motorist reaches the grade crossing, appropriate defensive action cannot be taken in time to avoid a collision. An important factor in motorist failure to detect an approaching train is the locomotive's lack of attention-getting visual properties, other than its standard headlight.

In 1991, the FRA initiated a locomotive conspicuity research program with the Volpe Center. In 1992, the U.S.

Congress required the Secretary of Transportation to complete locomotive conspicuity research and to issue interim regulations relating to locomotive conspicuity measures (Sections 202(u)(1) and 202(u)(2) of Public Law 102-5330) [3]. (This law was amended in 1994.) On February 3, 1993, the FRA issued a modification of the Code of Federal Regulations, Title 49 (49 CFR), Part 229, Railroad Locomotive Safety Standards, by the addition of Subpart 229.133, Interim Locomotive Conspicuity Measures--Auxiliary External Lights [4]. This Interim Rule (IR-1) identified, authorized, and encouraged the use of ditch lights, crossing lights, strobe lights, and oscillating devices as acceptable interim measures for locomotive conspicuity, and included a request for public comments. As a result of the public comments and preliminary results of ongoing research, the FRA issued an amended Interim Rule (IR-2) on May 13, 1994 [5]. This amended rule revised certain requirements described in the 1993 Interim Rule (length of grandfathering period, dimensional requirements for lighting placement, etc.). The FRA published a clarification relating to strobe light placement on August 4, 1994 [6]. Selection of the performance standards contained in the second Interim Rule was based upon the preliminary results of the Volpe Center study and an FRA analysis of public comments relating to auxiliary external alerting devices currently manufactured and available for use by the railroads. Appendix A contains a summary of the major provisions of the FRA 1993 and 1994 Interim Rules.

As part of the final rule-making proceeding, in addition to requiring the use of additional auxiliary external alerting light systems, the FRA was directed to consider: revisions to the current headlight standard, including placement and intensity; requiring use of reflective materials; requiring use of auxiliary lights to enhance locomotive conspicuity when viewed from the side; the effect of enhanced conspicuity measures on the vision, health, and safety of train crew members; and separate standards for self-propelled push-pull and multi-unit passenger operations without a dedicated head-end locomotive.

The FRA previously published rule-making initiatives in 1978, 1979, and 1982, related to the subjects of locomotive conspicuity and auxiliary external alerting light systems. However, public comments raised questions of alerting light effectiveness, cost, and reliability. The FRA subsequently withdrew these initiatives because the information collected at that point did not support the proposition that alerting lights were effective in reducing the incidence of highway-railroad grade crossing accidents. For example, various railroads conducted several tests of xenon strobe lights during the 1970s. The strobe lights often failed in cold weather and experienced other failures that affected operational reliability. A previous study [7] concluded that strobe-equipped locomotives in revenue service experienced fewer accidents per locomotive mile, though the sample used was too small to draw firm conclusions on a nationwide basis. Although other types of alerting light systems and reflective materials have not had extensive railroad testing, reflective materials have been tested on large trailers in a highway context [8].

Since locomotive conspicuity research (including controlled field tests and railroad revenue operational evaluations) was conducted in the early 1970s and 1980s, there have been many technological changes, both in the motor vehicle interior environment, and in alerting device material technology and techniques.

As noted previously, it is difficult for many motorists to perceive the hazard of a moving train, particularly at night. The use of higher intensity alerting lights and bright contrasting paint and/or stripes of reflective material increases locomotive visibility. However, light beam width, ambient light conditions, or grade crossing sighting angle are limiting factors. Glare which could potentially blind train crew or motorists is also a safety concern.

One technique used by some railroads is the alignment of alerting lights at an angle to produce a "crossed" effect, which provides a wider visible beam across the right-of-way in front of the locomotive.

1.2 OBJECTIVE

The objective of this study was to evaluate currently available auxiliary external alerting devices to provide the FRA with more definitive information for use in determining how these devices may improve locomotive conspicuity. The results of this evaluation are intended to assist the FRA in developing final regulations for auxiliary external alerting devices that will allow the motorist to: 1) detect the locomotive, 2) recognize the associated potential hazard, and 3) estimate train arrival time, in order to avoid a collision.

The FRA considered preliminary findings of this study in the process of issuing the 1994 revised Interim Rule. Final results of the study as described in this report were considered during the final rule-making process for locomotive auxiliary external alerting light standards.

1.3 APPROACH AND SCOPE

The Volpe Center used a multifaceted approach to evaluate how external alerting devices, i.e., auxiliary lights, paint schemes, and reflective materials (used in combination with the standard locomotive headlight), contribute to the ability of a motor vehicle driver to: (1) detect the approach of a locomotive before the train reaches the highway-railroad grade crossing, (2) recognize the associated potential hazard, and (3) and accurately estimate when the train will arrive at the grade crossing.

Chapter 2 discusses the factors that impact on the ability of the motor vehicle driver to take appropriate collision-avoidance action at a highway-railroad grade crossing. These factors are reviewed in terms of the effect on motorist information requirements for train detection, hazard recognition, and train arrival time estimation.

Chapter 3 presents an extensive review and assessment of locomotive visual active and passive alerting devices. Locomotive headlights (standard and oscillating), ditch lights, crossing lights, strobe lights, and front-end illumination, as well as paint schemes and reflective materials, are evaluated. International locomotive alerting devices are also described.

Chapter 4 presents a review of alerting light performance in terms of criteria contained within U.S. transportation modal agency regulations. The results of laboratory tests conducted for steady burn and flashing light components are also presented.

Chapter 5 presents the results of the controlled field test evaluation of observer behavior related to selected alerting light systems. Ditch, crossing, and strobe light systems (used in combination with the standard headlight), and the headlight alone used as a control, were tested under actual day and night ambient light conditions. Observer tasks included the peripheral detection of an approaching locomotive and the estimation of its arrival time during several random trials.

Chapter 6 discusses the results of an evaluation of auxiliary alerting light system in-service tests performed during actual railroad revenue operations. Three U.S. Class I railroads (CalTrain-Peninsula Corridor commuter service, Consolidated Rail Corporation, and Norfolk Southern Railroad) were selected for inclusion in the in-service tests. For each participating railroad, the characteristics of the test route segments and the alerting light systems that were installed and tested are described. The results of an evaluation of railroad capital costs, maintenance requirements, operational concerns, and accident data are presented.

Chapter 7 summarizes the report findings and provides conclusions for FRA consideration. Certain findings and conclusions of the initial draft report were revised to incorporate additional information as it became available before the publication of this final report.

2. MOTOR VEHICLE DRIVER BEHAVIOR AND LOCOMOTIVE CONSPICUITY

The behavior of the motor vehicle driver approaching a highway-railroad grade crossing can have a significant effect on the probability that a collision with a train will occur. Both active and passive roadside warning devices are used to indicate grade crossing locations. Additional motorist warnings (e.g., pavement markings, signs for no passing zones, and signs indicating the number of tracks) may also be used to increase motorist awareness of potential train movements and the hazards related to grade crossings.

Despite warning devices, a variety of motor vehicle driver errors may contribute to the failure to act in time to avoid a collision with a train. These errors include, but are not limited to: 1) failure to detect the train before the train reaches the grade crossing; 2) failure to recognize the potential hazard of a train; and 3) failure to correctly estimate when the train will arrive at the grade crossing. These errors can be traced in part to the quality of the train-related information (visual and audible) needed by the motorist to take appropriate action when approaching a highway-railroad grade crossing. The visibility of the train locomotive, configuration of the grade crossing, and the peripheral vision of the motor vehicle driver are all factors that impact on the motorist's ability to acquire the information necessary in time to avoid a collision.

The remainder of this chapter reviews factors related to locomotive conspicuity as they affect motorist information requirements for train detection, hazard recognition, and train arrival time estimation. If information about the approaching train is provided early enough before the motorist reaches the highway-railroad grade crossing, the motorist may be able to avoid a collision. Train visibility is a particular concern at passive grade crossings which are not equipped with active warning devices.

2.1 MOTORIST DETECTION OF LOCOMOTIVE APPROACH TO HIGHWAY-RAILROAD GRADE CROSSINGS

No matter how skilled the motor vehicle driver is, the physical environment of the highway-railroad grade crossing — terrain, structures, other roadways, and the presence of distracting signs and lights, as well as other motor vehicle and rail traffic — may contribute to collisions by reducing the visibility of the approaching train. In addition, poor visibility caused by low ambient light levels and environmental conditions (e.g., fog, rain) can impair the ability of the motorist to detect the train. Finally, the angle of approach of the grade crossing can make it difficult for a motorist to detect the approaching train within the field of the individual's vision.

It is essential that motor vehicle drivers detect possible train movements and recognize the associated dangers at highway-railroad grade crossings as early as possible in order to avoid a collision.

2.1.1 Locomotive Visual Characteristics

The visual characteristics of the locomotive play an important role in affecting when and if the motorist is able to detect an approaching train. Contrast of the locomotive with the background is one of the primary characteristics affecting its detectability. Increasing both the color contrast and brightness contrast between the locomotive and the background will increase the ability of the motorist to detect the train.

In the past, locomotives were often painted dark colors (e.g., black) to make dirt less noticeable between washings. This made the locomotive difficult to detect, particularly against a dark background (e.g., foliage, darkness). Contrasting paint schemes increase the visibility of the locomotive against both dark and light backgrounds, while the use of reflective (and retroreflective) material, if properly illuminated, can also provide improved attention-getting properties.

Detection of the train is more difficult at night, when the motorist can no longer see by the ambient light available. Traditionally, lights on the front-end of the locomotive are designed to help the train engineer see down the track rather than to make the locomotive more conspicuous to the motor vehicle driver. Railroad right-of-way lighting is typically nonexistent or poorly positioned to illuminate the locomotive. Headlights from the approaching motor vehicle are designed only to see the roadway ahead and so do not illuminate reflective material installed on approaching locomotives. Additional alerting devices mounted on the exterior of the locomotive, in addition to the headlight, can enhance its conspicuity by providing greater contrast with the background environment.

2.1.2 Highway-Railroad Grade Crossing Configuration

As the angle of the highway-railroad grade crossing diverges from 90^{o}, the portion of the visual field scanned on either side of the grade crossing becomes asymmetrical. Approaching the grade crossing, the motorist can scan the visual field more easily in one direction than in the other direction. To scan the visual field in the more difficult direction may require the individual to turn his or her head and look away from the road. Berg reported that fewer motorists look for trains when visibility is restricted [9]. This suggests that where the ability to look for trains is made more difficult by the geometry of the grade crossing, motorists are less likely to look for trains. The geometry of most grade crossings increases the motorist's reliance on peripheral vision to detect the train. Appendix B presents more detailed information concerning the impact on motorist visibility of three different types of grade crossing configurations: right angle, obtuse, and acute.

2.1.3 Motorist Peripheral Vision

Detecting an approaching locomotive in time to take appropriate collision-avoidance action requires that the motorist who is not actively looking for trains detect the locomotive using peripheral vision.

Zwahlen reports that the ability to detect a target declines as the target moves from the fovea (area of the eye with the highest visual acuity and contrast sensitivity) to the periphery of the visual field [10]. The foveal vision range is 0^{o} to 15^{o}, while the peripheral vision range is 15^{o} to 75^{o}, as illustrated in Figure 2-1. Thus, an object that is detected in foveal vision may not be detected in peripheral vision. Consequently, as an object moves further into the periphery of the visual field, greater contrast, size, and brightness are required for the person to detect its presence.

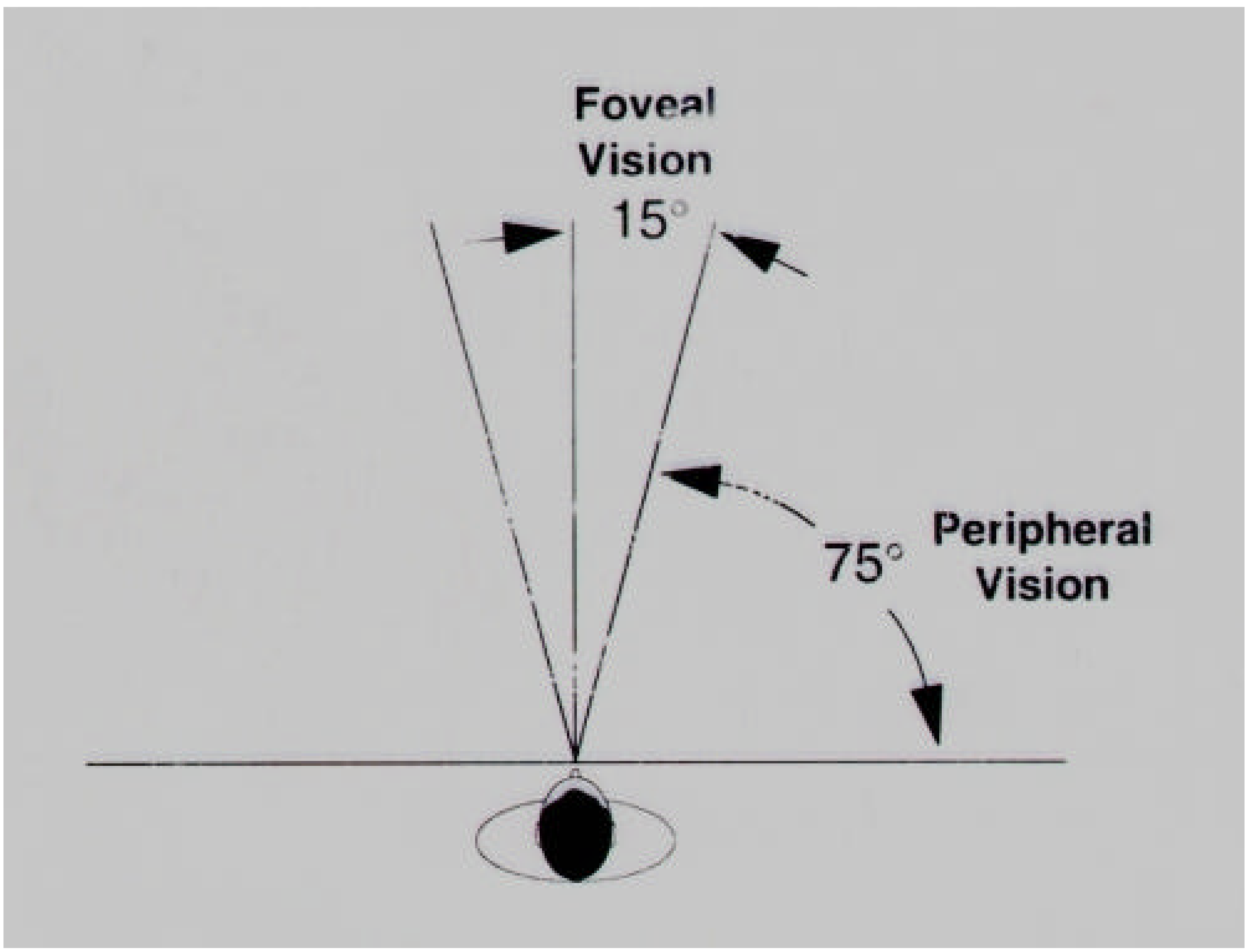

Figure 2-1. Peripheral Vision Range

The greatest number of highway-railroad grade crossings (79%) are configured between 60° and 90° [1]. To detect a locomotive traveling at 16 km/h (10 mph) that is 20 seconds and 89.4 m (293 ft) from a 90° crossing, a motorist located 213.5 m (700 ft) from the grade crossing would have to detect the locomotive almost 23° from the line of sight (see Figure 2-2). Under these conditions, the locomotive is outside the individual's foveal (center of) vision. For conditions where the locomotive is traveling faster than 16 km/h (10 mph) or the motorist is closer than 213.5 m (700 ft) from the grade crossing, the locomotive would be even further from the motorist's line of sight. Schoppert and Hoyt extensively discuss factors relating to sight and stopping distances as a function of the speed of trains and motor vehicles [11].

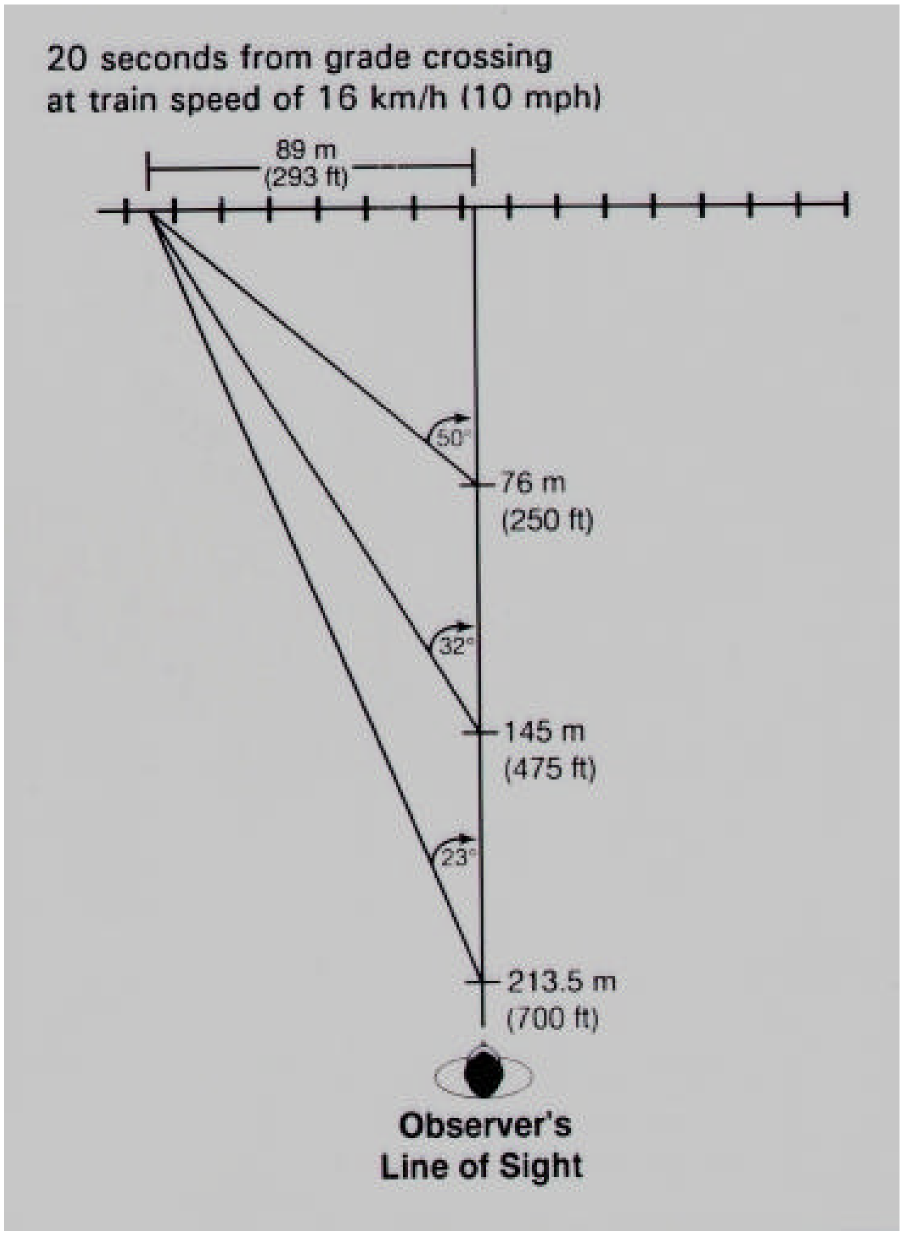

Figure 2-2. Observation Angle as a Function of Distance from Grade Crossing

Figure 2-2 illustrates how the reliance on peripheral vision increases as the motorist gets closer to the grade crossing. (Note: Sight obstructions could impact on peripheral vision.) Because attention is usually directed in a narrowly focused area, the motorist may not notice a train that is approaching from the periphery. To effectively use limited information-processing capabilities, the motorist pays more attention to some parts of the visual field than others. Portions of the visual field considered of secondary importance receive less attention than portions of the visual field considered more important (Howett et al.) [12].

In addition, encountering a train at a grade crossing is an unexpected event for many motorists. For unexpected events that occur in the peripheral field of vision, it takes a signal with greater impact to overcome the individual's low attention level and attract the motorist's attention (Leibowitz) [13].

The use of visual alerting devices on the exterior of the locomotive, such as additional lights, reflective material, and bright, high contrast paint (particularly if applied in a distinctive configuration), can significantly increase attention-attracting properties of the locomotive to the motorist in the peripheral field of vision. A multiple number of alerting lights supplies a broader spatial area coverage of the right-of-way ahead of the locomotive, thus providing a more noticeable advance signal to the motorist that a train is approaching the grade crossing.

2.2 MOTORIST RECOGNITION OF TRAIN HAZARD

The fixed track structure and the long stopping distances necessary for a typical train frequently prevent the locomotive engineer from avoiding a collision with a motor vehicle if the motorist fails to stop clear of the highway-railroad grade crossing. Because the motor vehicle driver has greater flexibility in avoiding a collision by stopping or turning away from a hazardous situation, the motorist has greater responsibility to avoid accidents at grade crossings. Moreover, many traffic laws require motorists to stop at grade crossings and/or yield the right-of-way to approaching trains.

The nature of roadway hazards is usually quickly perceived by motorists because of the presence of familiar warnings such as stop signs or traffic lights. However, warning indications for train movements which may occur are not always provided or visible at grade crossings or are not quickly perceived as a warning of an actual hazard. During daylight hours, the size of most locomotives provides motorists with an obvious indication of danger. However, the speed of the train, sight distance, the angle of road approach, and the presence of track curves, buildings, or vegetation may affect the motorist's ability to see the locomotive or the train, and recognize the associated danger. Moreover, under conditions of decreased visibility (e.g., darkness, rain, or fog), if locomotive lights are detected, the motorist must identify the point source of the lights as belonging to a locomotive. However, the motorist may not realize that the approaching lights belong to a train. At night, during conditions of darkness, the different light configurations currently installed on many locomotives do not present a uniform signal to the motorist that make them easily identifiable.

Auxiliary external alerting light systems installed in a standard, distinctive configuration can provide the motorist with a means to recognize the hazard of an approaching train under all ambient light conditions. Figure 2-3 illustrates the pattern on the front end of a locomotive which a triangular arrangement of alerting lights would provide.

2.3 MOTORIST ESTIMATION OF TRAIN ARRIVAL TIME AT GRADE CROSSING

After detecting the train and recognizing it as a hazard, the motorist must decide whether or not to stop before the grade crossing or proceed. In many grade crossing accidents, there was clear warning of the train's approach [13]. However, the motorists chose to ignore the warning and proceeded across the grade crossing, failing to clear the track in time to avoid a collision.

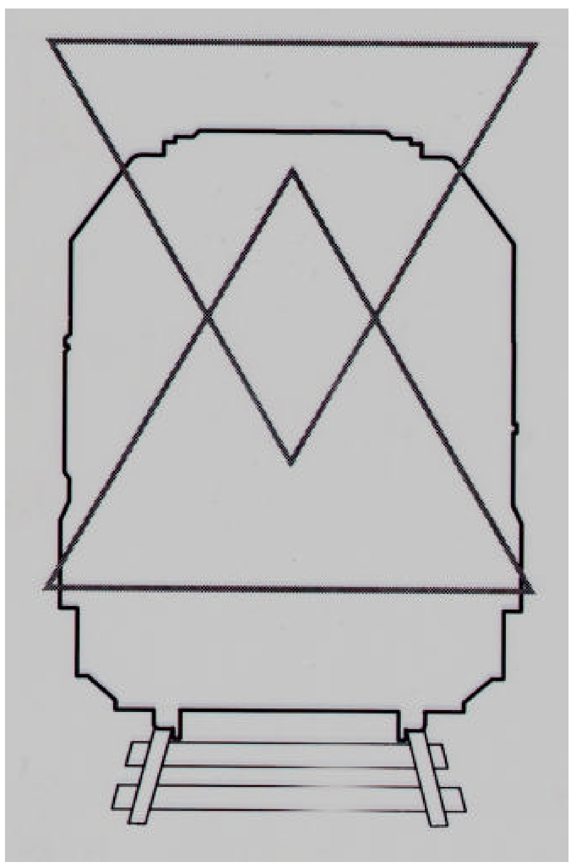

Figure 2-3. Triangular Locomotive Light Pattern

The decision to stop or continue through the grade crossing depends, in part, on the motorist's estimate of the train's arrival time at the grade crossing, and the motorist's estimate of the time required for the motor vehicle to clear the grade crossing. A motorist's estimate of the train's arrival time can be influenced by the visual information presented to the motorist by the train and its visual warning devices.

The motorist's accuracy in judging when the train will arrive at the grade crossing can vary from underestimation to overestimation. For example, consider the case where the train is actually 7 seconds away from the grade crossing (i.e., time to arrival equals 7 seconds).

Underestimation occurs when the motorist's estimate is less than the actual locomotive arrival time. A motorist who estimates that the train is 5 seconds from the grade crossing underestimates the time to arrival by 2 seconds, since the train arrives later than expected. In contrast, overestimation occurs when the motorist's estimate is more than the actual locomotive arrival time. A motorist who estimates that the train is 9 seconds from the grade crossing overestimates the time to arrival by 2 seconds, since the train arrives sooner than expected.

Underestimation and overestimation each have different consequences for the motorist. Underestimation gives the motorist more time than expected to make a decision to stop or continue through the grade crossing. More time increases the margin of safety by providing the motorist a longer time to act to avoid a collision. Overestimation provides the motorist less time than expected to make a decision to stop or continue through the grade crossing and is therefore more likely to result in a train-motor vehicle collision.

Certain systematic biases contribute to the overestimation of arrival time. One bias arises from the perception of velocity and size. As objects increase in size, they appear to move more slowly. Due to more frequent exposure, motorists are experienced at judging the velocities of motor vehicles that are smaller than the train. If the train is perceived to be moving more slowly than it is, the locomotive will appear farther away than it actually is. As a result, the motorist overestimates the arrival time. Finally, for an object heading straight toward the observer at a constant velocity, the expansion of the object changes as it moves closer.
This change in the rate of expansion provides information about arrival time. However, the rate of expansion is variable. Leibowitz suggested that the rate of expansion increases slowly at the point the motorist commonly makes the decision to stop or to proceed through the grade crossing [13]. As a consequence, the motorist overestimates train arrival time.

The use of appropriate auxiliary external alerting devices may help the motorist estimate the train's arrival at the grade crossing. If such alerting devices can provide information to more accurately perceive train velocity, they can improve motorist judgment.

In a study measuring the accuracy with which observers perceive time to train arrival at the grade crossing based upon a locomotive's alerting device, Sanders et al. found differences in accuracy that varied by device [14]. In addition, the Sanders study concluded that motorists consistently underestimated arrival time, regardless of the alerting system used. This finding contradicts Leibowitz's contention that motorists overestimate arrival time.

An explanation for this discrepancy concerns the approach trajectory of the train. The Sanders study examined the situation where the observer is close to the grade crossing (9 m [30 ft]) and looking directly at the oncoming train. However, in order to avoid a collision, the individual must decide whether it is safe to proceed through the grade crossing from a much greater distance away. As a result, the motorist may not have a frontal view of the approaching train because the train may be in an oblique or transverse position relative to the motorist.

The accuracy of estimating arrival time varies with the approach trajectory of the object relative to the observer (Schiff and Oldak) [15]. In judging arrival time to an object, Schiff and Oldak found observers underestimating the time to objects judged approaching head-on (0^o) and overestimating arrival time to objects in a transverse (angled) orientation. Observers more accurately judged events in the transverse orientation. Underestimation of arrival time to objects approaching frontally is supported by other studies as well (MacLeod and Ross; Loomis, Fujita, et al.) [16, 17]. However, this underestimation of train arrival time found in the Sanders study may not be representative of real-world behavior, since the motorist typically must decide to proceed through the grade crossing much farther away from the crossing, where the approach trajectory of the locomotive may not be head-on.

2.4 SUMMARY

Existing literature suggests that locomotive visibility, highway-railroad grade crossing configuration, and motorist peripheral vision affect the ability of the motor vehicle driver to detect a train approaching a grade crossing, recognize the potential hazard of the train, and estimate its arrival time. Remaining chapters of this report describe the results of a multifaceted study conducted by the Volpe Center to evaluate different types of locomotive auxiliary external alerting lights and their effect on motorist ability to obtain information which will assist in avoiding a collision with a train at a grade crossing.

3. LOCOMOTIVE VISUAL ALERTING DEVICES

Historically, standard locomotive headlights have provided a visual signal of the approach of a train to a motorist at a highway- railroad grade crossing, although headlights are not designed for that purpose. In contrast, emergency motor vehicles such as police cars, fire department vehicles, and ambulances commonly use special types of alerting lights, as well as paint schemes and reflective materials, to provide an advance warning signal to motorists. Various types of alerting devices are used to provide warning signals to aircraft pilots and marine vessel operators. Steady burn and flashing lamps of various colors, as well as rotating beacons and strobe lights are examples of alerting lights used to increase vehicle visibility. Factors which affect alerting light visibility to the observer include the number of lights, light output (intensity), steady burn or flashing aspect (flash frequency and duration), spatial separation, and geometric pattern. A triangular configuration of lights which provides an otherwise rarely encountered signal has been previously proposed for emergency motor vehicle warning lights to increase conspicuity [11]. In addition, trucks are required to use outline and side lights, as well as reflective materials, to make motorists more aware of the nature and size of the vehicle, thus increasing their recognition and comprehension of hazards related to those vehicles [18]. The primary function of all of these alerting devices is to attract the motorist's attention to the vehicle and the potential special circumstance or hazard in order to prevent collisions.

This chapter presents the results of a review and assessment of several types of active and passive external alerting devices and their use on locomotives in major U.S. railroad operations. Findings of previous investigations relating to the effectiveness of many of these devices are summarized. International alerting devices are also reviewed. Selected candidate auxiliary external alerting device systems are identified for further testing and evaluation.

3.1 ACTIVE AND PASSIVE ALERTING DEVICES

Active alerting devices supply the light source to the observer while passive alerting devices rely on light from other sources to reflect the light to the observer. Different railroads operate various numbers and types of active and passive locomotive alerting devices based on operating environment, costs, etc. The standard headlight required by the FRA is designed to help the train engineer see down the track; it provides a very limited alerting function to the motor vehicle driver. Historical use of alerting lights by the U.S. railroad industry include: oscillating lights, rotating beacons, strobe lights, crossing lights, ditch lights, and ground lights. Figure 3-1 shows the typical location of the standard headlight and various alerting lights installed on the front end of a locomotive.

Passive alerting devices include paint schemes and reflective materials, used alone or in combination. Figure 3-1 shows the typical location of reflective material on the front of the locomotive as installed by several U.S. railroads. Again, use varies according to operating railroad.

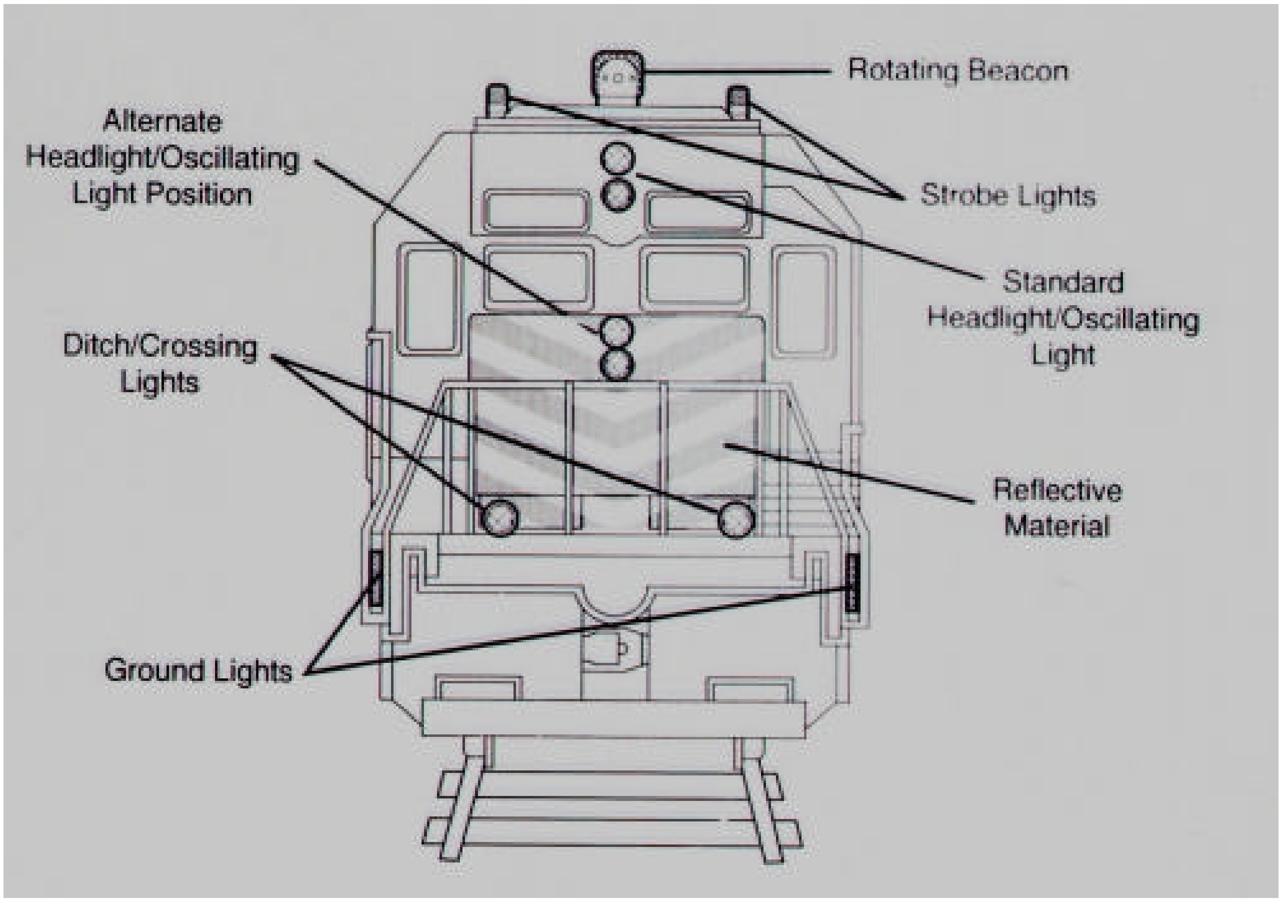

Figure 3-1. External Locomotive Alerting Devices (Lights and Reflective Material)

3.2 STANDARD HEADLIGHT

The standard railroad locomotive headlight is designed to illuminate the track area directly in front of the train to permit the train engineer to see a specified distance ahead in order to see signals and otherwise operate the locomotive in a safe manner.

On locomotives used in road service, standard dual, sealed beam, incandescent headlights are mounted together, either horizontally or vertically, on the front of the locomotive. Headlights are generally mounted near the top of the crew cab or below the crew cab on the nose of the locomotive. Some railroads are beginning to replace the standard 200-watt bulbs with brighter 350-watt bulbs. The FRA, in Part 229.125 of 49 CFR [2], requires that the luminous intensity of the headlight beam of each lead locomotive used in road service be at least 200,000 candela*; the light must be arranged to illuminate a person at least 244 m (800 ft) ahead and in front of the headlight. The FRA requires that the headlight luminous intensity for locomotives used in yard service be 60,000 candela; the light must be arranged to illuminate a person at least 91.5 m (300 ft) ahead and in front of the headlight. The railroad industry operates road locomotives and yard locomotives with the headlight continuously turned on. The FRA requires a dimmer switch; this is used to operate the headlight at low beam at night and when passing oncoming locomotives.

The standard locomotive headlight is aimed down the track center-line and has a narrow, horizontal 3.5^{o} beam width, as shown in Figure 3-2.

A variation of the locomotive headlight is the oscillating light (see Section 3.3.1). Oscillating lights have a narrow beam width similar to the standard headlight.

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* "Candela" is defined as the metric power output unit of luminous intensity (photometric brightness) produced by a light source. Chapter 4 and the glossary further explain lighting terms.

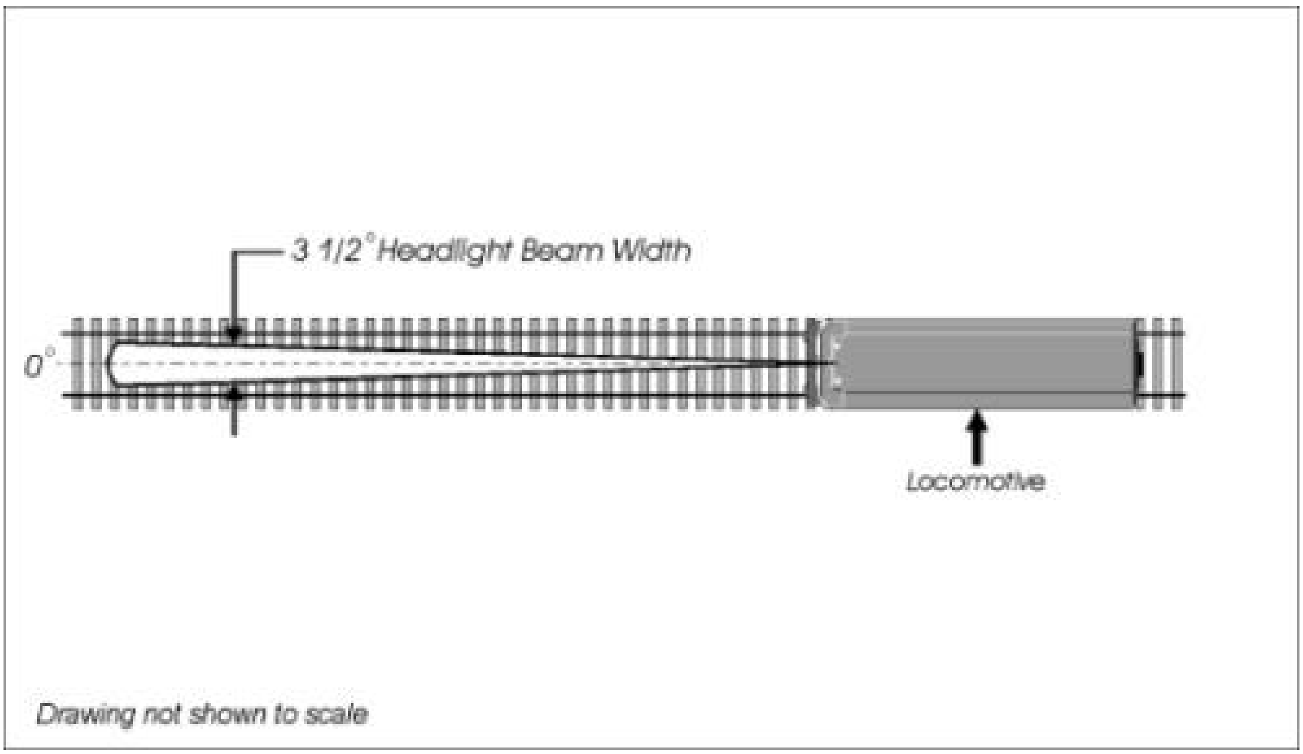

Figure 3-2. Standard Headlight Beam Width/Focus Angle

The standard headlight can provide a visual signal to motorists at grade crossings to indicate the approach of a train. However, the single point source of light, narrow beam width, and focus angle limits the ability of a motorist to recognize the approach of the locomotive or estimate its rate of approach.

3.3 AUXILIARY EXTERNAL ALERTING DEVICES - OVERVIEW

Active auxiliary external alerting devices (i.e., lights) supply the visual signal to the motorist in the form of a light source which may differ in number, intensity, location on the locomotive, beam width, and focus angle. The observation angle at which the visual signal is observed by the motorist can vary, depending on the grade crossing geometry. The specific operation of these alerting light systems varies but either of two aspects may be displayed: steady burn or flash. Both FRA Interim Rules specify the color, operational aspect, and minimum horizontal and vertical spacing of auxiliary external alerting light systems, in relation to the required standard headlight. The 1994 Interim Rule requirements are intended to provide a distinctive triangular pattern which will permit the motorist to recognize the approaching train, as well as its general location relative to the grade crossing. As noted previously, the triangular light "cluster" configuration was initially identified as a shape which could make emergency motor vehicles more conspicuous. The spatial dimensions required by FRA are based on the visibility formula contained in the *IES Lighting Handbook* [19].

The various types of auxiliary external alerting lights used in U.S. railroad operations are described below.

3.3.1 <u>Oscillating Lights</u>

Oscillating lights use standard incandescent headlight components, mounted on the front of the locomotive (see Figure 3-1), aimed down the track centerline, and in some cases, mechanically turned to sweep across the train path. Oscillating lights are considered to be an alerting light in both FRA Interim Rules. The lights are designed so that the moving beams rapidly reflect off of and illuminate objects in front of the train (e.g., trees, buildings, and signs), thus providing a "startling" effect to motorists.

The FRA 1994 Interim Rule describes two types of acceptable oscillating lights: (1) one steadily burning white light in a moving beam that depicts either a circle or a horizontal "figure-eight" near the longitudinal centerline of the track in front of the locomotive; or (2) two or more white lights located at the front of the locomotive, alternately flashing with beams within 5^{o} horizontally to either side of the longitudinal centerline of the track. These configurations illuminate a slightly greater track area than the standard headlight.

The FRA Interim Rules require that both the single, steady burn oscillating light and each of the two flashing lights of the second type of light produce at least 200,000 candela.

3.3.2 Rotating Beacon Lights

Rotating beacon lights use two designs. In both, the beacon is mounted on the top of the locomotive as far front as possible, on the centerline of the locomotive (see Figure 3-1). The first beacon design mechanically rotates a single beam of light, produced by an incandescent roof lamp with a vertical filament, 360^o within a housing. The second design uses four sealed beam light sources and electronically actuates each beam randomly. One variation of both designs, the bipolar radial beacon light (BRB), is housed within a structure of alternating vertical red and clear filters. When the light source is activated, a changing aspect (red and white) is provided to a stationary observer. The FRA does not include rotating beacon light standards in its Interim Rule requirements.

3.3.3 Strobe Lights

Locomotive strobe lights frequently use a clear ("white") xenon tube (recommended as a result of FRA-sponsored research conducted in the 1970s). The FRA 1994 Interim Rule requires that the clear xenon flash tube stroboscopic lights flash at a minimum rate of at least 40 flashes per minute and a maximum of 180 flashes per minute. The lights may be positioned in pairs, one on each side, on the roof (as shown in Figure 3-1) or on the lower front end.

A previous FRA study recommended that locomotive-mounted strobe lights operate at two intensities depending upon ambient light: (1) 100 to 400 effective candela* during night conditions, and (2) 800 to 4,000 effective candela during day conditions [20].

The FRA Interim Rules require an effective intensity of not less than 500 candela for strobe lights.

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* "Effective candela" is the unit which equates the visual effect of a flashing light to that of a steady light. Chapter 4 and the glossary further explain lighting terms.

3.3.4 Ground Lights

Low-intensity locomotive exterior side lights were historically known as the "American-style" ditch light. However, the term "ground lights" is used in this report to denote any 15- to 20-watt lights located underneath the locomotive sill. (See Figure 3-1.)

As shown in Figure 3-3, the lights are aimed toward the ground and the beam focus is designed to illuminate the immediate area of the track and right-of-way, near the crew stairway, to enhance train crew safety in mounting and dismounting from the rear or head-end of the locomotive.

Due to their low intensity and beam direction, ground lights are not considered effective in enhancing locomotive conspicuity to motorists and are not included in the FRA Interim Rules. Accordingly, ground lights are not discussed further in this report.

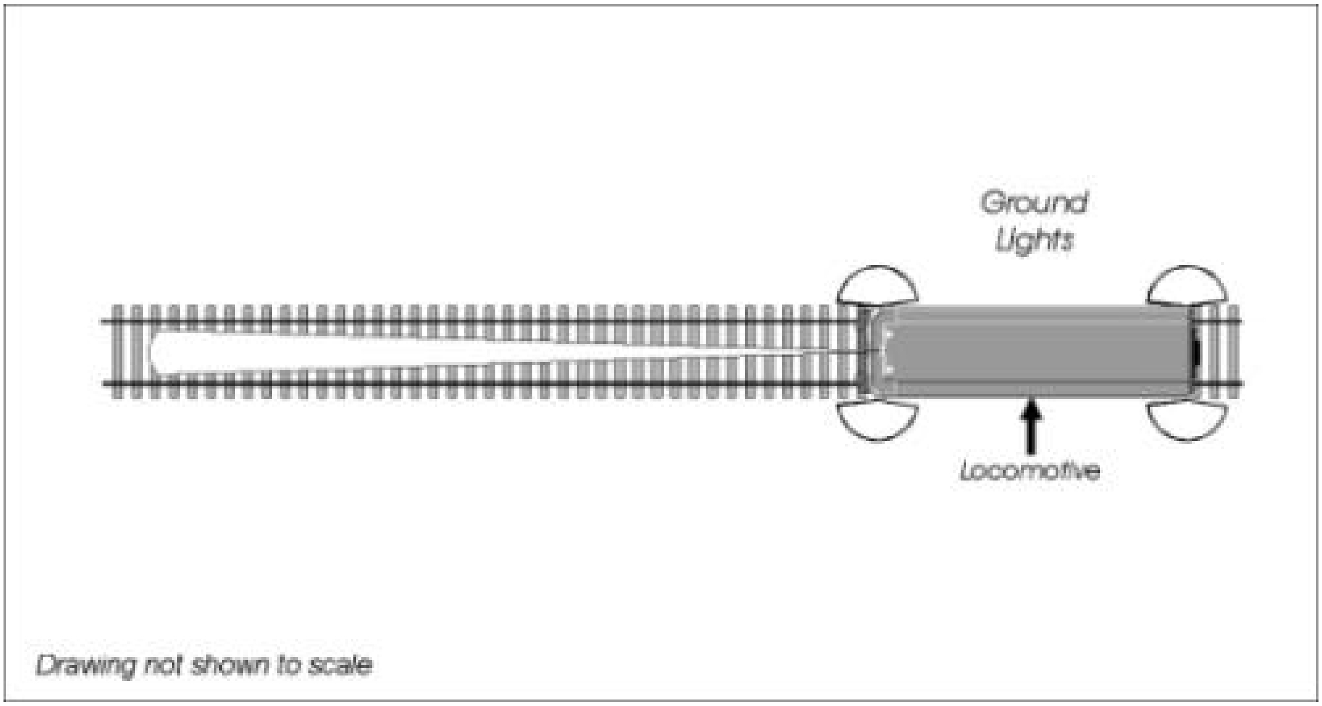

Figure 3-3. Ground Light Beam Focus Angle

3.3.5 <u>Ditch Lights</u>

"Ditch light" refers to the "ditch" or the area of the right-of-way located immediately forward of the locomotive, to either side of the track that this light illuminates.

3.3.5.1 "Canadian" Ditch Lights

Following a Canadian train derailment in 1974 caused by a mountain landslide [21], the use of ditch lights on Canadian locomotives was required by the Canadian Transport Commission which determined that better visibility of the right-of-way could have prevented the accident. The Canadian Pacific (CP) ditch lights are about 153 cm (60 in) apart and about 153 cm (60 in) above the top of rail. The focus angle is adjusted inwardly so that the ditch light beams cross at

45.8 m (150 ft) in the horizontal plane and strike the opposite rails at 92 m (300 ft) in the vertical plane [22]. Figure 3-4 illustrates that the resulting wider light beam path illuminates a larger track area ahead of the train.

3.3.5.2 U.S. Ditch Lights

The U.S. ditch light system is also specifically designed to illuminate the part of the track right-of-way lying outside the area normally illuminated by the standard headlight. U.S. ditch lights are located on each side of the front of the locomotive (Figure 3-1). The FRA Interim Rules specify that each ditch light must produce a steady beam of at least 200,000 candela. The lights must also be focused horizontally within 45^{o} of the longitudinal centerline of the locomotive.

Figure 3-5 illustrates the beam pattern of the ditch light at its widest allowable focus angle from the centerline.

U.S. ditch lights typically use the same 200- or 350-watt sealed beam found in the standard headlight and thus share the same narrow beam width.

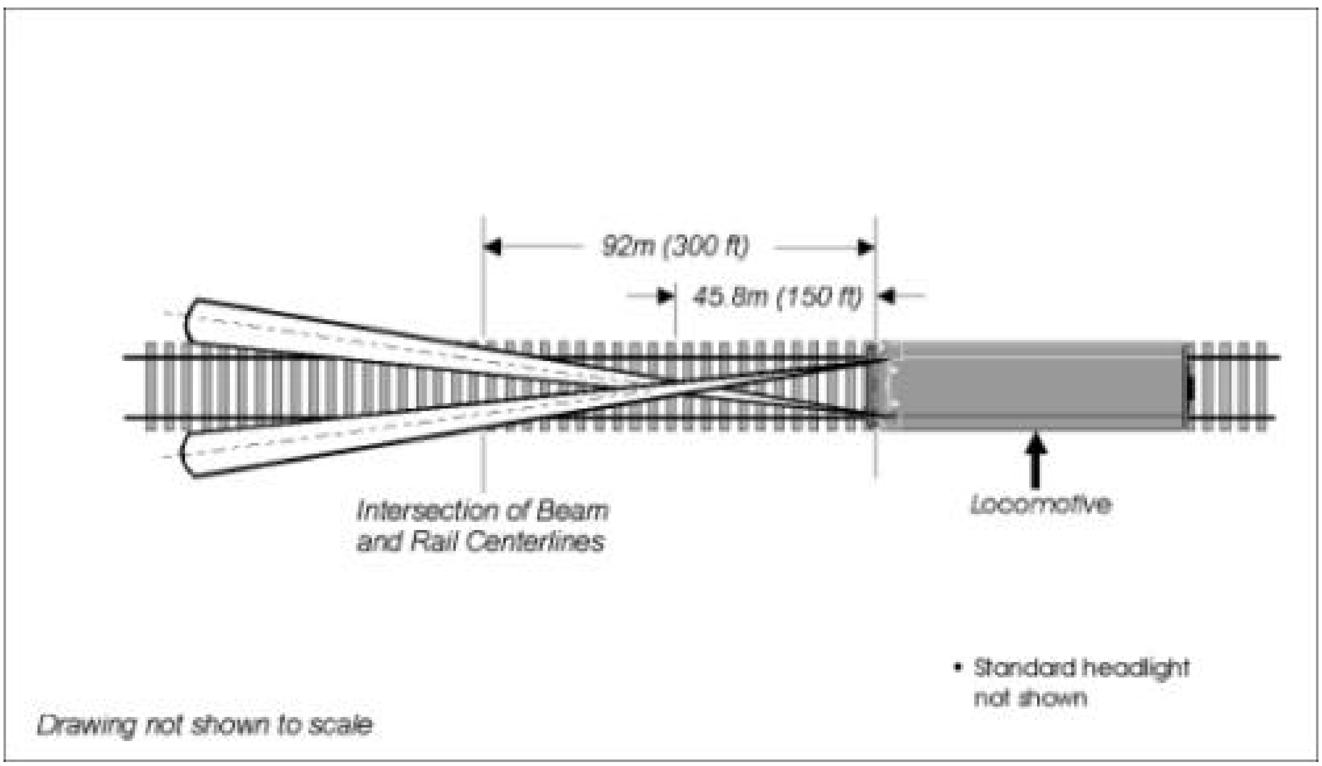

Figure 3-4. "Canadian" Ditch Lights - Beam Focus Angle

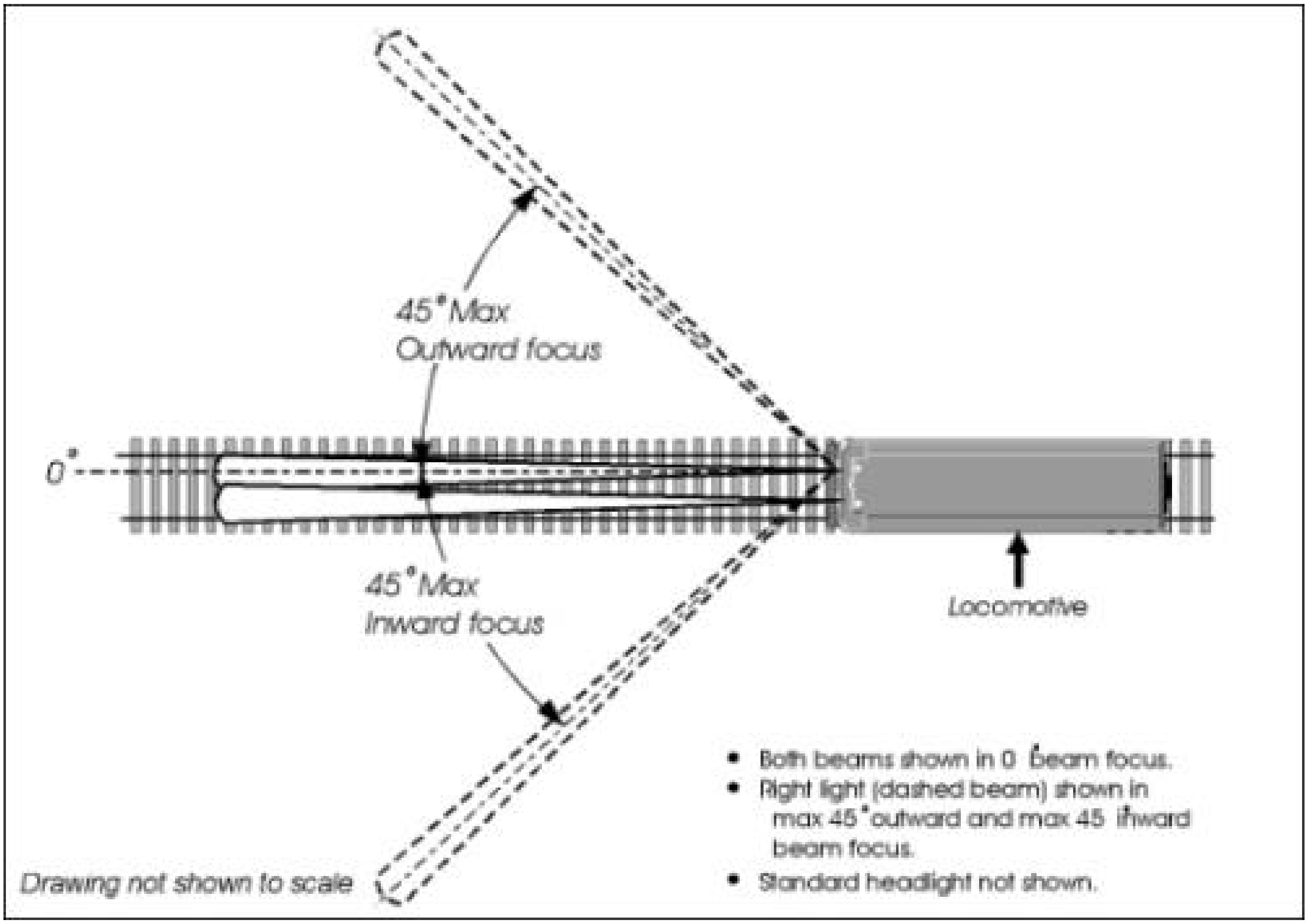

Figure 3-5. U.S. Ditch Lights - Maximum/Minimum Beam Focus Angle

3.3.6 Crossing Lights

The U.S. crossing light system is similar to the ditch light system in that it illuminates the part of the track right-of-way lying outside the area normally illuminated by the standard headlight. U.S. crossing lights are located on each side of the front of the locomotive (Figure 3-1).

The FRA Interim Rules require that each crossing light produce at least 200,000 candela in either steady burn or flashing modes. In addition, crossing lights must be focused horizontally within 15^{o} of the longitudinal centerline of the locomotive. The flash rate of crossing lights must be least 40 flashes per minute (maximum 180 flashes per minute). Figure 3-6 shows the crossing light beam angle focus at 0^{o} and 15^{o}.

Crossing lights typically use the same 200- or 350-watt sealed narrow beam found in the standard headlight, thus sharing the same narrow beam width.

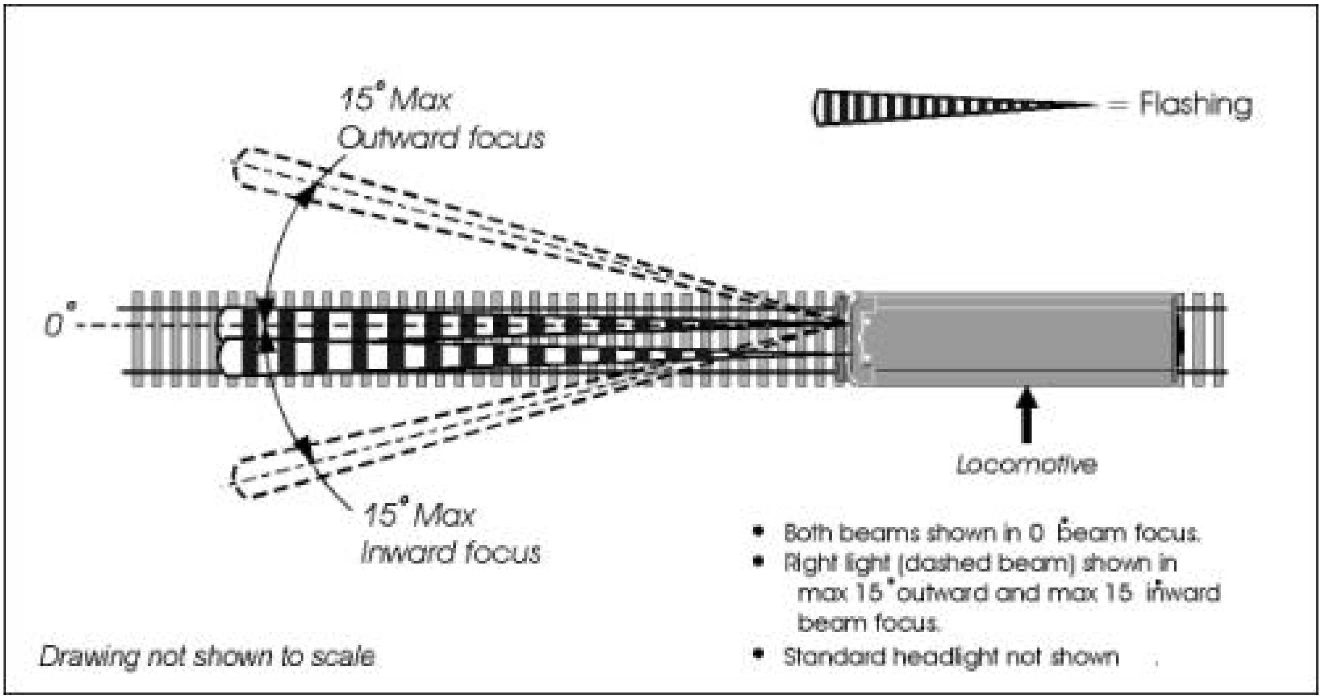

Figure 3-6. Crossing Lights - Maximum/Minimum Beam Focus Angle

3.4 INTERNATIONAL ALERTING DEVICES

Locomotives used in international railroad operations are equipped with various types of alerting devices to permit the motor vehicle driver to see the train approaching the highway-railroad grade crossing. (Canadian alerting lights are previously discussed in Section 3.3.5.1).

3.4.1 International Union of Railways (UIC)

The International Union of Railways (UIC) specifies headlamp provisions for locomotives, rail motor vehicles, and motor-coach trains in UIC Code 534 [23]. In the "alerting" mode, the headlamp provides a signal to be used by external observers who would look at the light source (e.g., motorists or track crew workers). The provisions are obligatory for new powered units and recommended for existing power units used in international traffic. UIC Code 534 requires that locomotives, rail motor vehicles, and motor-coach trains be equipped with two electric signal lights placed on the same horizontal plane, at a height above rail level of between 1.5 and 1.7 m (59 to 67 in). The spacing of the two lights must be as wide as possible, without falling below 1.3 m (51.2 in); 1 m (39.4 in) is allowed for streamlined trains. In addition to these two signal lights, a third signal light must be placed at each end, in the upper central section of the powered unit locomotives, rail motor vehicles, and motor-coach trains, which are likely to be operated on certain railways (e.g., Germany, Austria, Netherlands). The arrangement of the three signal lights forms a triangular light pattern which is illustrated in Figure 3-7.

UIC Code 534 requires that each of the two lower signal lights be fitted with an aspect changeover device enabling either a white or red aspect, except when the signals consist of superimposed optical lenses. The lights must also not be "dazzling" (i.e., not produce excessive or objectionable glare).

Figure 3-7. UIC Locomotive Triangular Light Pattern (Germany)

In addition, the signal light aspect diameter must be a minimum of 17 cm (6.7 in), and the minimum lower white light intensity in the centerline must be between 300 and 400 candlepower while the upper signal light must be between 150 and 200 candlepower. The light intensity must be between 20 and 40 candlepower at 45^o on either side of the centerline in a horizontal direction. Finally, the provision for an electrically operated switching device enabling the signal lights to function as projectors (i.e., as headlights) is permitted.

3.4.2 Great Britain

British requirements for the visibility of approaching trains as perceived by people on or near the track are defined in a Railtrack Railway Group Standard [24]. This Railtrack Standard includes mandatory provisions to make the approaching train clearly distinctive by virtue of the front-end color and the presence and layout of the front (signal) lights. The approaching train running at maximum speed must be visible to people on or near the track for at least 25 seconds under daylight, night, and all intermediate ambient light conditions. The Railtrack Standard provides pre-determined sight distances for eight train speeds; the required distance for the maximum train speed of 120 km/h (75 mph) is 1,600 m (5,248 ft), while for the minimum train speed of 32 km/h (20 mph), the required distance is 300 m (984 ft). The train must also be visible from the predetermined distances in daylight, fog, rain, and falling snow except when the daylight visual range is reduced to less than 1,500 m (4,920 ft). The Railtrack provisions relating to front-end paint color are reviewed later in this chapter (see Section 3.6).

The Railtrack Standard requires that two signal lights be placed as close as possible to the outside edges of the front of the leading vehicle of the train, positioned so that they are not obstructed. The light centers must be no less than 1.3 m (51 in) apart, laterally equidistant from the vehicle centerline as viewed from the front, and must also be neither higher than 1.75 m (69 in) nor lower than 1.5 m (59 in) above the top of rail.

To provide a distinctive light formation (i.e., triangle) to indicate the approaching lights are on a train, the Railtrack Standard requires that a third signal light (of lower intensity than the other two), be mounted high on the leading vehicle front (in accordance with UIC Code 534).

At least one of the three lights must be of sufficient intensity to provide the 25 second approach warning; the intensity of the other lights may be lower but must still allow visual separation of the lights at the approach distance. The lights must be of a white color; each of the front lights designed for use at night shall not achieve a glare illuminance of greater than 0.4 lux at the eyes of an approaching train engineer on a parallel straight track; the limit is 1.7 lux per light for a light designed for use as a temporary replacement for a failed night lamp.

For the lower two signal lights, the minimum and maximum light luminous intensities at 0^{o} from the centerline and 1^{o} down from the horizontal plane are required to provide a 25 second sighting of the train approach for a particular distance, as a function of ambient light and train speed. To provide the 25 second, 1600 m (5,248 ft) required distance for daytime speeds of up to 225 km/h (140 mph), the minimum and maximum luminous intensities required are 50,000 candela and 70,000 candela, respectively. In contrast, to provide the 25 second sight distance for: (1) nighttime operation with the same speed — up to 225 km/h (140 mph) and same sight distance — 1,600 m (5,248 ft), and (2) for daytime operations at a speed of 200 km/h (125 mph) for a 1,400 m (4,592 ft) sight distance, the minimum and maximum intensities are reduced to 35,000 candela and 50,000 candela, respectively. The required intensity of the third signal light is lower with no variation for ambient light, speed, or distance, with a minimum of 1,200 candela and a maximum of 8,000 candela at 0^{o}, both from the centerline and down from the horizontal plane.

All of the alerting lights must be continuously illuminated; the train engineer is provided with a switch to control the lights in various operational modes as follows: (1) turn all the lights off, (2) turn the two lower lights on, (3) use daylight intensity mode, and (4) use night intensity mode. The latter two settings permit a change of luminous intensity for ambient light conditions and speed, as required by the Railtrack Standard.

According to Railtrack staff [25], the British signal lights are steady burn lights which are turned on at all times when trains are moving and are not switched off or dimmed when passing opposing trains. The lower minimum and maximum intensities at night are used to eliminate unacceptable glare to train engineers of oncoming trains on adjacent tracks for train speeds between 160 to 225 km/h (100 to 140 mph). The nighttime light intensity is also considered suitable for daytime use at train speeds less than 160 km/h (100 mph) [24].

The Railtrack Standard also requires a hazard warning control to warn an oncoming train of a perceived hazard; this switch allows simultaneous flashing of all lights or two lights at a frequency of 40$\pm$ 10% cycles per minute. The lights must continue to flash until turned off while each on/off cycle must allow the lamp filaments to be fully on and off in each cycle.

3.4.3 Australia

Controlled field trials of Australian locomotive auxiliary alerting lights were completed in 1992 [26]. The four types of lights tested were: Light 1, 70-watt standard locomotive headlight; Light 2, 100-watt standard locomotive head-light; Light 3, 100-watt higher intensity driving lights (with pencil beam); and Light 4, 100-watt combination driving/fog lights. Stationary observers viewed the locomotive approach at points 65 m (213 ft) and 150 m (492 ft) away from the cross road; locomotive operating speed was a constant 80 km/h (48 mph). A pair of each type of light was mounted below the headstock (sill) of the locomotive, at 1.1 m (43.3 in) above the top of rail, and was tested in combination with the standard headlight. In initial daytime tests, the light systems were mounted parallel to the centerline of the track to form a triangular light pattern with the standard headlight. The parallel mounting (0^o) of the lights was reported to provide little or no warning to the motorist. Tests were then conducted at night with the alerting lights pointed 7.5^o and 15^o horizontally to the outside of the centerline of the track, and 7.5^o and 15^o horizontally toward the inside of the track to make the alerting lights appear "cross-eyed."

According to the Australian status report, light focus angle outward tended to make only one alerting light visible to observers

around curves. It was concluded that the Light 4 (100-watt combination driving/fog lights) system of two lights angled 7.5^o inward (cross-eyed) provided "ample" warning to motorists and improved track illumination directly ahead and to the side for the locomotive engineer.

The Australian status report stated that the cross-eyed light system was considered "more appropriate" than the other light system configurations for the following reasons:

- It maintained the "triangle of light" — especially with the cross-eyed 7.5^{o} inclination — more consistently over a greater distance.
- It did not "blind" the observer (e.g., motorist) at various distance/inclination combinations due to excessive intensity.

Figure 3-8 shows the Australian alerting light system "cross-eyed" beam focus angle.

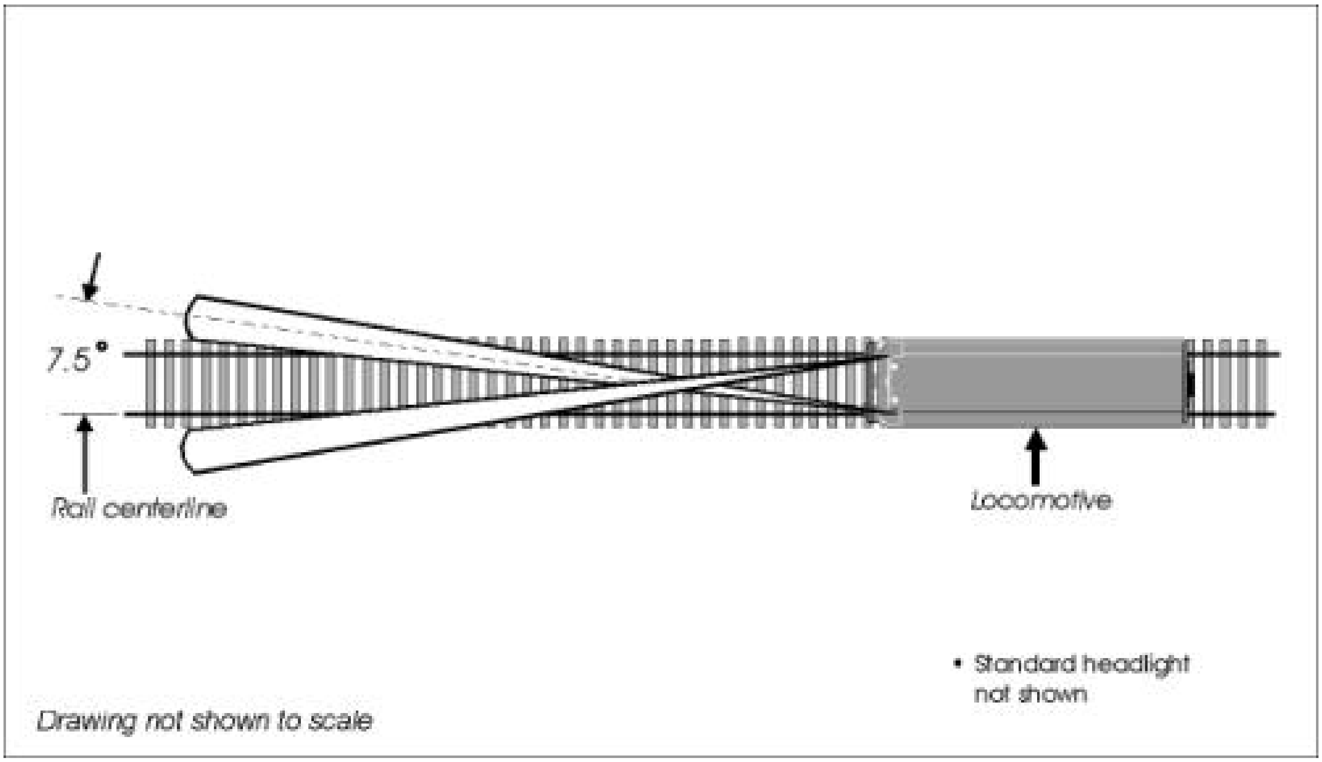

Figure 3-8. Australian Alerting Light Beam Focus Angle

3.5 EXTERNAL ALERTING LIGHTS - ANALYSIS

The previous sections described characteristics of standard locomotive headlights and several types of auxiliary external alerting light systems currently used in U.S. and international railroad operations to enhance locomotive conspicuity. The next section provides an analysis of these light systems.

3.5.1 Standard Headlights, Oscillating Lights, Rotating Beacon Lights, and Strobe Lights

The standard U.S. locomotive headlight, whether stationary or oscillating, is extremely bright, but its single point source of light with a narrow beam width limits detection by motorists unless their vehicles are stopped at the grade crossing. The single point light source conveys very little information to the motorist to either recognize the hazard of an approaching locomotive or estimate its arrival time.

The results of two 1974 and 1975 FRA studies indicate that the bipolar radial type of rotating beacon lights are objectionable to train crews as a result of the striped pattern that is projected when the locomotive was moving (Sanders et al. and Hopkins and Newfell, respectively) [14 and 20]. Moreover, mechanically operated rotating beacons are more expensive to maintain. An independent study conducted at the University of the South stated that, used alone, rotating beacons are easier to locate visually than the strobe light (due to their producing 18 times more total light per flash) [27]. The study concluded, however, that the strobe light had a distinct advantage in bright sunlight, as well as in adverse conditions such as fog, rain, or smoke, because of its higher peak intensity. In addition, the rotating beacon lights provide limited alerting effectiveness due to the exhibition of a negligible flashing effect to motorists. Lastly, due to the complexity of moving parts, maintenance is more of a concern for rotating beacon lights than with other types of alerting lights.

Several other studies have concluded that strobe lights provide an especially effective alerting light for enhancing locomotive conspicuity. The 1971 Aurelius and Korobow study concluded that only strobe lights were "effective" in attracting motorist attention in daylight because conditions of bright sunlight require a very intense beam to be directed at the motorist [28]. The final recommendation of that study was for the use of a pair of roof-mounted xenon strobe lights, flashed alternately, and actuated only when the train is moving. Dual lights aid the motorist in estimating the distance to the locomotive from the grade crossing. A 1973 study by Hopkins concluded that the overall effectiveness of the strobe light was "very good," based on increased visibility exhibited under darkness, twilight, bright sunlight, and heavy overcast conditions [29]. The issue of light "effective intensity" was reviewed. The intensity level required for a strobe light to be seen in bright sunlight would be quite high — too high for nighttime use; some automatic or manual adjustment would be advisable to reduce the effective intensity.

The 1974 Sanders et al. study used stationary observers to evaluate six light systems, including two types of strobe lights, mounted on a moving locomotive under darkness and daylight conditions at different viewing angles [14]. The "fast" strobe had a flash rate of 150 cycles per minute (cpm) while the "slow" strobe light flashed at 60 cpm. The study included observer estimation of arrival time versus actual arrival time of the locomotive. One conclusion of the study was that the "fast" strobe light ranked significantly higher in visibility than the other light systems. The fast strobe also resulted in the smallest number of over-estimation errors, increasing the motorist safety margin.

In a 1975 study, Hopkins and Newfell concluded that strobe light effectiveness in attracting motorist attention is due to both the broad horizontal beam sweep and the flashing effect [20]. The desirability of a multiple-intensity lamp and its relatively low cost was noted. The study states that reducing effective intensity to a range of 100 to 400 candela at night should eliminate all train crew annoyance, while an effective intensity of 800 to 4,000 candela would be preferred for daytime operation. Automatic changeover of effective intensity of the light system was recommended with a manual override. The study also concluded that strobe lights increased the conspicuity of the trains, especially at night. However, the findings were based on subjective evaluations by observers and train crews, rather than controlled, quantitative tests.

The 1975 Devoe and Abernethy study evaluated locomotive xenon strobe lights on a stationary locomotive [30]. The strobe lights were viewed by volunteers who drove an automobile across two sets of railroad tracks, during day, dusk, and night ambient light conditions, from a distance up to 402 m (approximately 1,320 ft) away from the locomotive. Under all these conditions, the volunteers reported that the strobes were "readily visible and attention-getting." Again, these were subjective evaluations by observers and train crews, rather than controlled, quantitative tests. It was noted that an excessively brilliant light may be glaring or blinding, particularly to the dark-adapted eye at night. The relatively high effective intensities required for fog or some daylight conditions were indicated as being higher than desirable for normal night conditions. A two-level system with automatic adjustment was suggested.

A 1980 study by Hopkins involved revenue operational testing of locomotive strobe lights [7]. The strobe lights tested had a daytime effective intensity of 800 to 1,200 candela for five of the six test configurations with 1,600 effective candela for the exception. The effective intensity for night was 200 to 400 candela for all six tests. As noted in the previous studies, the strobe lights appeared to exhibit maximum effectiveness at night, and no adverse effects were reported by the train crews. The use of multiple effective intensities so that high brightness levels could be used in daytime with much lower values at night was noted as a positive factor to limit train crew exposure.

The results of the 1980 Hopkins study also indicated that for all of the three participating railroads, there were fewer accidents per locomotive mile for strobe-light-equipped locomotives than for unequipped locomotives. Due to the limited number of locomotives (20 to 40 for each railroad), low number of accidents per million train miles, different operating environments and related reliability issues, the narrow sample precluded the inference that results would be similar if the strobe lights were used nationwide.

3.5.2 Ditch Lights and Crossing Lights

A test of Conrail "ditch" lights (both steady burn and flashing) was conducted in 1992 [31]. A luminance meter was used to measure the luminance of the "ditch lights," strobe lights, and the standard headlight (high beam) on a locomotive located at distances ranging from 823.2 m (2,700 ft) to 152.4 m (500 ft) away from a rural 90^o angle grade crossing. A significant improvement in comparative and contrast luminance by the steady burn and flashing mode of the lights tested over the standard headlight was identified. The luminance meter could not pick up the flashes (due to the short duration of the pulse) of the strobe light and thus the output could not be measured.

Limited controlled field testing conducted in Australia identified a "cross-eyed" ditch light configuration as effective in enhancing locomotive conspicuity, as well as reducing glare to the motorist and locomotive engineer.

No quantitative evaluation of U.S. crossing light or ditch light system performance using observers has previously been performed. Furthermore, no quantitative analysis of accident data has previously been available for U.S. railroad operations using locomotives equipped with the FRA-defined crossing or ditch light systems, or other innovative alerting light designs.

3.5.3 Triangular Light Pattern

A standard arrangement of three alerting lights in a triangular pattern is used on the front of European and Australian locomotives. The distinctive pattern enhances the motorist recognition of the presence of an approaching train. The *Manual on Uniform Traffic Control Devices* recognizes the importance of uniformity and pattern to achieve effective results in motorist behavior [32]. Uniformity also lowers costs by reducing installation and maintenance procedures, and provides a defense against possible adverse judgments in tort liability cases.

The FRA 1994 Interim Rule establishes a uniform distinctive pattern by requiring spacing requirements for two ditch, crossing, or strobe lights, which, in combination with the headlight, form a three-light triangle. Neither type of oscillating light, if used as a variation of the standard headlight, will permit the required FRA triangular pattern display unless it is used with a pair of the ditch, crossing, or strobe alerting lights. Although the second "two oscillating light" configuration could provide a triangle shape if used in addition to the standard headlight, the FRA 1994 Interim Rule does not include a requirement for spacing between these lights, as is included for the other alerting lights.

3.6 PASSIVE EXTERNAL AUXILIARY ALERTING DEVICES - REVIEW AND ANALYSIS

Locomotives are typically painted dark colors (i.e., black) to make the dirt and grime that accumulate between washings less noticeable. Passive auxiliary alerting devices, such as contrasting paint schemes and reflective materials, can be used to increase the contrast of the locomotive for both dark and light background operating environments.

3.6.1 Paint Schemes

U.S. railroads have implemented different paint schemes using bright stripes with contrasting colors, such as red and white, on a diagonal pattern across the front of locomotives. However, the width of the stripes affects conspicuity. In addition, the effects of weathering degrade the intensity of the paint, despite washing.
The alerting qualities of paint schemes are extensively discussed in the Aurelius and Korobow train visibility study [28]. That study also cites several references as the basis for certain paint scheme recommendations to improve U.S. train visibility. This section highlights pertinent points of the Aurelius and Korobow report and the requirements contained in the British Railtrack Standard [24].

3.6.1.1 Aurelius and Korobow

The visibility of an object depends on brightness (intensity) and color (hue). Although color is a more dominant visual signal than brightness, brightness intensity is more important for maximizing visual acuity (visual resolution) against a background for observers. A locomotive with low brightness is more conspicuous against a light background (e.g., cloudy sky) than a dark background (e.g., foliage). Conversely, a locomotive with high brightness is more conspicuous against a dark background. Use of hues not commonly found in nature is recommended. Yellow, white, or fluorescent yellow/orange are recommended light hues; red, blue, and black are suggested dark hues. Brightness contrast is also essential for colorblind motorists who cannot differentiate contrasting colors. Approximately 8% of males and 0.5% of females have some form of color acuity deficiency [33].

As no single color maximizes detectability under all visibility conditions, Aurelius and Korobow recommend using two contrasting colors in bold patterns, as shown in Figure 3-9 (a). For example, if the upper and lower bands are dark blue and the middle band is yellow, the dark bands will provide good contrast against bright surroundings and the bright yellow will provide good contrast against dark surroundings. Aurelius and Korobow state that it is important to use wide bands of contrasting color since narrow diagonal stripes lose their value longer distances away from the locomotive (see Figure 3-9 (b)). The color blocks for contrasting colors should have minimum dimensions of 1.07 m

(3.5 ft) vertically by 1.5 m (5 ft) horizontally to be visible 305 m (1,000 ft) away from the observer. For contrasting colors to be effective, it is important to select one color with a low brightness value and one color with a high brightness value.

3.6.1.2 Railtrack Standard

The Railtrack Standard recognizes that train visibility color arrangements vary according to the locomotive sight distances

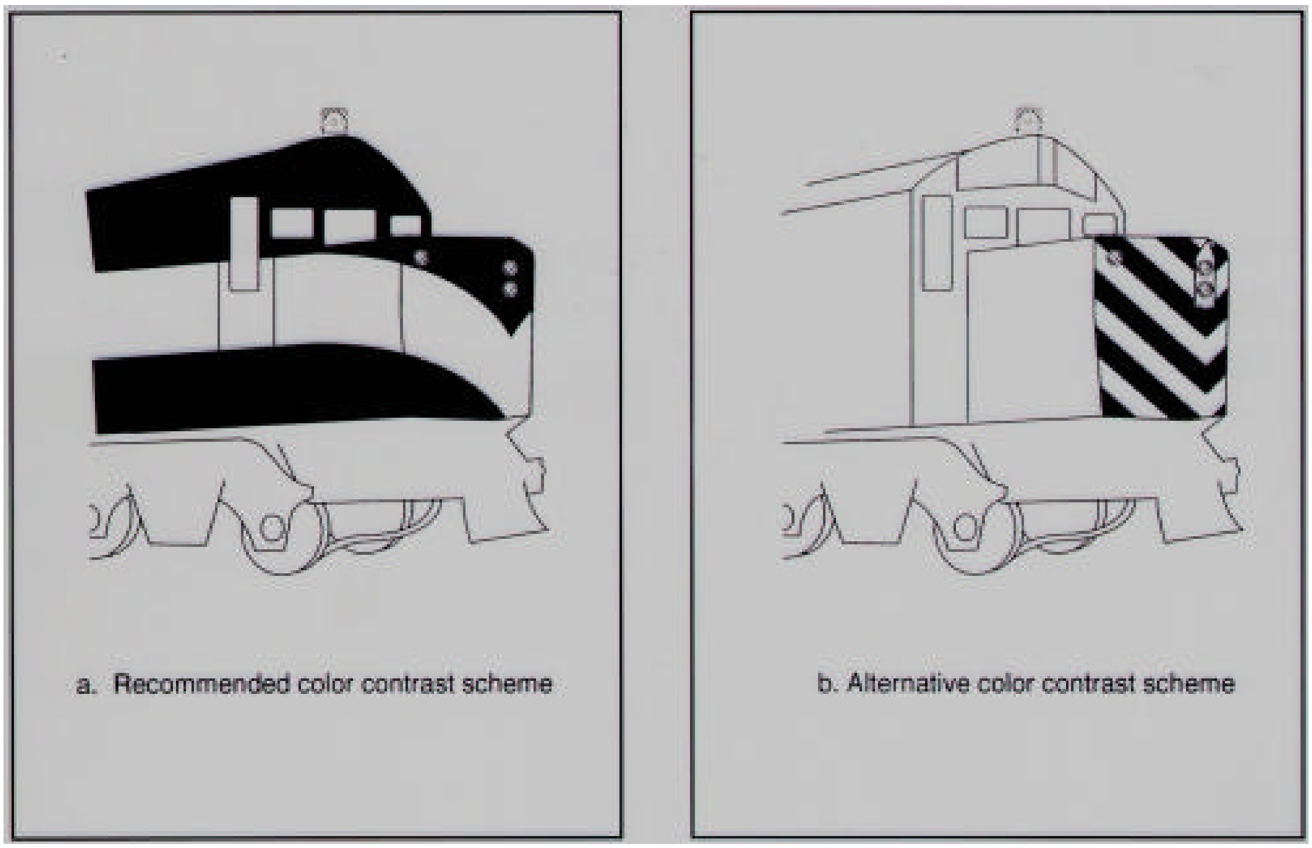

Figure 3-9. Locomotive Paint Schemes

required which vary as a function of train speed [24]. The forward facing front end of a British train must exhibit a warning yellow color; a risk assessment is also required to determine the color dimensions and areas as they relate to train speed and the 25 second visibility time, as specified by predetermined locomotive approach sight distances. The Railtrack Standard requires that, at a minimum, as much as possible of the front end should be yellow. The minimum surface area must be 1 m^2 (10.7 ft) with a minimum dimension of 0.6 m (1.97 ft). For high-speed trains (operating at +160 km/h (100 mph), the yellow warning color must continuously cover the extreme vehicle front, including the cab roof.

For medium-speed British trains up to 145 km/h (90 mph), the Railtrack Standard requires some yellow/black color contrast to aid visibility to achieve the 25 second approach sight distances.

In addition, the Railtrack Standard requires a yellow and black striped arrangement for shunting locomotives. Minimum stripe widths and vertical angles are specified for four train speeds ranging from 32 to 95 km/h (20 to 60 mph) to provide the 25 second warning.

3.6.2 Reflective Materials

Reflective material can be mounted onto the front and sides of a locomotive to increase its visibility. However, reflective material returns light in a diffused or scattered manner, making it more difficult for an observer to see the light in peripheral vision. In addition to the reflective material, an external light source is also required, such as motor vehicle headlights, to provide visibility.

Reflective materials in the form of retroreflective sheets are often mounted on the sides of the locomotive. Retroreflective materials return a particularly bright beam of light from the source (e.g., the motor vehicle headlights) directly back to the motorist, rather than scattering it [30]. However, the narrow observation angle causes the level of light reflection to decrease rapidly as the individual moves away from the light transmission axis. For example, the observation angle for prismatic retroreflective materials is approximately 0.2^{o}. To effectively illuminate this material, the motor vehicle headlight must be aimed almost directly at the retroreflective materials. Due to the configuration of the grade crossing (e.g., the track elevation or angle in relation to the roadway) and motor vehicle headlight focus, the ability of the motorist to see the retroreflective material may be limited.

Reflective materials are also available which disperse reflected light over a very wide area. However, because the light from the source is diffuse, the reflected light intensity decreases even more rapidly as a function of distance and angle, than with retroreflective materials.

The results of a recent Norfolk Southern Railroad comparison of grade crossing accidents for a nine-month period in 1993 (January through November) using 50 locomotives with front ends equipped with reflective logo decals versus 50 equipped with painted non-reflective decals showed no difference in the number of grade crossing acccidents [34].

Another conspicuity enhancement concept involves an external light source, other than the motor vehicle headlight, aimed directly at reflective material at the front end of the locomotive. This front-end illumination of the locomotive must provide for sufficient light reflection to attract the motorist's attention and allow for the detection of an approaching train in peripheral vision. Front-end illumination, used in combination with paint and reflective material requires the careful choice of a brilliant contrasting paint scheme and/or reflective material on the front end of the locomotive so that there is a sufficiently bright surface to illuminate. In placing the lights, care must be taken to avoid impairing the vision of the locomotive engineer, particularly during precipitation (e.g., fog, rain drops, or snowflakes), which tends to scatter the light. The effectiveness of retroreflective materials applied to the locomotive front end and illuminated by train-mounted lights is affected by the observation angle. The angle at which train-mounted lights are positioned and the design specifications of the retroreflective material determines the angle at which the motorist will observe the light reflected from the locomotive. As discussed previously, the actual observation angle is so narrow that the reflected light can be detected only within a limited range. Outside this area, light intensity decreases dramatically as the observer moves away from the axis along which the light is directed.

3.7 FINDINGS

A variety of active and passive external alerting devices have been reviewed and evaluated in terms of their potential effectiveness for enhancing locomotive conspicuity.

Only the British Railtrack Standard identifies mandatory provisions to make the approaching train clearly distinctive. The Railtrack Standard requires the use of bright front-end color <u>and</u> the presence and layout of the front (signal) lamps, in order to provide a 25 second warning to an observer, as a function of train speed, sight distance, and ambient light.

3.7.1 <u>Alerting Lights</u>

Past studies of available alerting lights indicate that the very narrow beam width and focus angle of conventional locomotive headlights used in U.S. and international operations, even of the oscillating variety, do not provide effective warning to the motor vehicle driver, unless the motorist is stopped near the highway-railroad grade crossing. These studies also indicate that the mechanically operated rotating beacon lights are more expensive to maintain than strobe lights. The dual color flashing effect of the bipolar radial beacon lights was judged by train crews to be extremely distracting.

In contrast, several studies have identified the use of roof-mounted xenon strobe lights mounted on the locomotive as an effective means to alert the motorist to the approach of the train before it reaches the grade crossing.

Train speed, sight distances, and ambient light conditions affect the ability of an external observer to detect an approaching locomotive. Accordingly, different minimum and maximum intensity levels for steady or flashing light systems may be appropriate for day and night operation to reduce unacceptable glare to engineers of oncoming trains and motorists.

A distinctive arrangement of three alerting lights in a triangular pattern has been used for several years on the front of European locomotives. Such a distinctive and uniform pattern enhances the ability of motorists to: (1) detect the train, (2) recognize the approach of a train as a potential hazard, and (3) estimate the train arrival time at the grade crossing. The FRA 1994 Interim Rule incorporates the three-light pattern by including triangle dimensional specifications for ditch, crossing, and strobe lights, to be used in combination with the standard locomotive headlight.

The preliminary results of alerting light tests performed in Australia indicate that the inward cant of alerting lights enhances locomotive conspicuity, as well as reduces glare to the external observer (e.g., train engineers and motorists.)

Prior to the study documented in this report, no U.S. evaluation had been conducted to quantify the relative effectiveness of crossing lights and ditch lights in aiding motorists to detect an approaching locomotive and estimate its arrival time to a highway-railroad grade crossing. In addition, accident data for actual railroad operations was not available to validate the relative effectiveness of crossing or ditch lights, as compared to each other, or to standard headlights or strobe lights.

Accordingly, ditch and crossing light systems were selected as candidates for further testing and evaluation. These light systems will be compared with strobe lights and the standard headlight. Chapter 4 of this report compares FRA, Federal Aviation Administration (FAA), and United States Coast Guard (USCG) alerting light usage and performance characteristics and presents the results of Volpe Center laboratory tests conducted to measure the brightness of the lamp bulbs used in the standard headlight, the ditch and crossing lights, and the strobe light. Chapter 5 presents the results of a controlled field test evaluation of these alerting light systems using stationary observers and moving locomotives. Chapter 6 describes the results of the in-service railroad operational tests and includes an analysis of accident data compiled for locomotives equipped with and without crossing light systems.

3.7.2 Passive Devices

Although passive alerting devices can be used to enhance locomotive conspicuity, particularly during daylight conditions, several factors may decrease their effectiveness. These factors include maintenance (the locomotives must be washed frequently with appropriate cleaning materials) to ensure continued brightness, color contrast, and a high level of reflectivity. In addition, the focus angle (straight ahead) of the motor vehicle headlight and site-specific grade crossing configurations may limit the available angular sight distance necessary for motorists to detect an approaching locomotive equipped with reflective material. The limited Norfolk Southern Railroad evaluation involving reflective decals versus painted nonreflective decals installed on locomotives did not show a reduction in grade crossing accidents.

Finally, limited sight angles diminish the effectiveness of train-mounted front-end lights to enhance brightness, color contrast, and reflectivity. Accordingly, it was determined that further testing and evaluation of passive alerting devices was outside the scope of this study.

A parallel study is being conducted by the Volpe Center under FRA sponsorship to provide additional information relating to reflective materials used on freight cars. The results of this study may be transferable to assist the FRA in further addressing locomotive side reflectorization.

3.8 CONCLUSIONS

The results of the review of active and passive alerting devices indicate that alerting light design and operation can improve locomotive conspicuity. Locomotive alerting light systems provide additional information for motorists to: (1) detect the locomotive, (2) recognize the potential of the hazard, and (3) estimate approaching train arrival time and thus avoid a collision with a train at highway-railroad grade crossings.

The following specific conclusions are presented for consideration by the FRA in its development of final regulations for locomotive conspicuity:

- Passive alerting devices are considered to be of only limited effectiveness in enhancing locomotive conspicuity. Accordingly, locomotive passive alerting devices should be used only as a secondary technique to reduce collisions at highway-railroad grade crossings.
- The use of auxiliary external alerting lights can be an effective means to improve locomotive conspicuity.

- The use of either type of oscillating headlight, as described in the FRA Interim Rules, does not provide the FRA-specified triangular alerting light pattern.

- Multiple lights, light intensity, spatial dimensions and angle, and pattern all contribute to increasing the effectiveness of the visual alerting signal and thus make the approaching locomotive more noticeable to motorists.

- Train approach speed, sight distances, and ambient light conditions should be considered when specifying minimum and maximum levels for alerting light luminous intensity and effective intensity.

- The provision of a low-beam intensity control which supplies a lower luminous intensity level for the entire alerting light system, similar to the "dimmer" switch currently used for the standard headlight, would reduce the potential for glare.

- A "cross-eyed" alerting light beam pattern with lights angled inward and focused an extended distance down the track appears to have the positive features of a wider system beam width and range in front of the train as well as less potential for blinding motorists.

4. ALERTING LIGHT PERFORMANCE CONSIDERATIONS

Visual detection and recognition of an approaching hazard by means of warning signals, such as external alerting lights, play a major role in avoiding collisions between transportation vehicles. Freight and passenger train, aircraft, and marine vessel external alerting light systems consist of steady burn or flashing signals; different colors are used for aircraft and marine vessel lights. This chapter discusses alerting light performance criteria and summarizes Federal Railroad Administration (FRA), Federal Aviation Administration (FAA), and US Coast Guard (USCG) alerting light performance requirements. In addition, the results of a laboratory evaluation of selected components of external alerting light systems used to improve locomotive conspicuity are presented.

4.1 PERFORMANCE CRITERIA

The ability of an observer to visually detect a light source is based on the luminous intensity (optical power output) of the light. The luminous intensity of a steady burn light source is expressed in units of "candela." The optical power output of a flashing light is measured differently than a steady burn light because of flash rate effects and the duration of each flash. The optical power output of a flashing light source is defined in terms of "luminous energy" (or effective intensity) and is expressed in units of "effective candela."

The apparent luminous intensity of a flashing light with a rating of 100 effective candela is such that it is seen to be as bright as a 100 candela steady burn light, when viewed from the same distance or having the same visual range.

The FRA, the FAA, and USCG, and the National Institute of Standards and Technology (NIST) all use the Illuminating Engineers Society (IES) approved method for determining effective candela for flashing light source intensities to predict the effective intensity or visible range of flashing warning (alerting) lights [35].

The Aviation Committee of the Illuminating Engineering Society's (ACIES) guide for calculating the effective intensity of flashing signal lights provides a basis of comparison for the characteristics of these various types of light sources [36]. The guide provides a uniform methodology by using the Blondel-Rey formula to calculate the effective intensity of flashing lights for comparison with steady burn lights. The methodology prescribed in the ACIES guide was used to analyze laboratory results described in subsection 4.3 for selected alerting light components which can enhance locomotive conspicuity.

4.2 DOT ALERTING LIGHT PERFORMANCE REQUIREMENTS

The FRA, FAA, and the USCG have issued performance requirements for light systems in terms of candela (units of luminous intensity) for steady burn lights, and in terms of effective candela (units of luminous energy) for flashing lights. Table 4-1 contains a summary of DOT agency requirements described in the following subsections.

Table 4-1. DOT Agency Performance Requirements for Alerting Light Systems

DOT AGENCY	**CANDELA** (Steady Burn)	**EFFECTIVE CANDELA** (Flashing)	**FLASH RATE PER MINUTE** (Flashing)
FRA	200,000	500	40 to 180 cpm
FAA	40	400	40 to 180 cpm*
USCG	94	94	60 cpm

* The maximum FAA flash rate per minute is 100 cycles per minute (cpm). The maximum is increased to 180 cpm if overlapping flashing lights exist in the system.

The following discussion reviews the DOT agency requirements in terms of two light system functional requirements for each mode. The first functional requirement is the provision of a "navigation" light system (e.g., "aids to navigation" is the term used by the FAA and USCG) for operator use in controlling the position and direction of her or his vehicle or vessel. These "aids to navigation" light systems are briefly reviewed since they may affect the total amount of light output received by an external observer of transportation vehicles or vessels.

The second functional requirement is to provide an "anti-collision" alerting light system for use by an external observer to see the vehicle or vessel and avoid an impact with it.

Both the "aids to navigation" and "anti-collision" functional requirement definitions, as well as the luminous intensity and effective intensity definitions described previously, provide a context for the following discussion of FRA, FAA, and USCG alerting light regulations.

Flashing lights are a better means to alert an outside observer to the presence of a vehicle or vessel or structure, but steady burn lights provide the observer the opportunity to fix her or his attention on a point source of light to determine the rate of approach of the train, airplane, or vessel. The FRA, FAA, and USCG use different types of light systems due to the different operational environments unique to each transportation mode.

The potential blinding effect of the alerting light caused by focus angle and/or high intensity is also an important safety issue for all transportation mode alerting light systems. Glare is the result of an increase in luminance within the visual field that is sufficiently greater than the luminance level to which the external observer's eyes are already adapted. Glare can reduce visibility and impair operating performance as well as annoy the operator of a vehicle or vessel. The magnitude of the sensation of glare depends upon factors such as the size, position, and luminance of a source of light, and the number of sources and the luminance to which the observer's eyes are adapted [19].

Disability glare refers to glare that impairs visibility and interferes with task performance. There are two types of disability glare [37]. One occurs when scattered light enters the eye and reduces the contrast of the object being viewed. The other type occurs when an observer's eyes are attracted to a bright light source (such as an alerting light), which is brighter than the surrounding field of view. In practical terms, the effects of glare will depend upon the intensity of the glare source. Olson and Aoki report that when the glare source is a motor vehicle halogen lamp meeting SAE specifications, over 3.5 seconds is necessary to recover from a low beam glare and over 5 seconds to recover from a high beam glare [38]. Measures to avoid or minimize glare produced by alerting lights include directing the light away from the observer, and reducing the light intensity level.

4.2.1 "Aids to Navigation" Light Systems

All three of the DOT agencies — the FRA, FAA, and the USCG — require lights for the use of the operator to control the position and direction of the vehicle or vessel, i.e., "aids to navigation."

The FRA requires that the locomotive headlight (steady burn) used for road service have a luminous intensity of at least 200,000 candela. The headlight light focus angle in the horizontal plane in relation to the centerline of the locomotive must illuminate the track so that the locomotive engineer can identify moving or stationary objects or conditions at a distance of 244 m (800 ft) in front and ahead of the locomotive. The reduced luminous intensity (60,000 candela) and distance requirements (91.5 m [300 ft]) for railroad yard headlight operation is required to reduce excessive glare for railroad employees.

The FAA performance requirements for airplane aids to navigation light systems are contained in 14 CFR, Part 25, Subparts 25.1383-1395 [39]. These systems consist of steady burn lights and include landing lights, as well as red, green, and white position lights. Minimum luminous intensities for steady burn landing lights are not specified, but require enough light for night landing with no "objectionable glare visible" to the pilot. The FAA requires that each of the two steady burn position lights be located on the front of the airplane as wide apart laterally as possible, with each light to have a minimum luminous intensity of 40 candela within 10^o of the centerline of the airplane. The third position light must be white and steady burn, and must be located on the rear of the airplane. In addition, the FAA specifies maximum intensities for overlapping beams of the position lights.

USCG light system requirements are contained in 33 CFR, Parts 62, 67, 81, and 84 [40, 41, 42, and 43]. The USCG requirements for aids to navigation light systems vary from the FRA and FAA requirements. This different approach may be due to the different background luminance existing in the marine operating environment, different operating procedures, and the need to mark areas of hazard (e.g., low water depth).

Accordingly, the USCG does not require the installation of any positional or directional navigation lights on the marine vessel itself. Instead, lights are placed onshore or on marine sites to mark limits of navigable channels, or to warn of dangers or obstructions. The vessel operator maneuvers the ship or boat towards a specific position or in a particular direction by sight (or radar), using colored markers (e.g., buoys) and beacons located on marine sites as reference points. (Beacons and buoys may be lighted or unlighted.)

The USCG requires that steady burn green and red lights be used for aids to navigation lights (Subpart 62.45) [40]. The vessel is required to pass to the left or right of the aids to navigation lights depending on the vessel direction. The USCG specifies a regularly flashing or occulting aspect and different colors for light types used for certain other aids to navigation; these aids include those with lateral significance (not to exceed 30 flashes per minute) and isolated danger marks (flashing, white). For cautionary aids (e.g., indicating sharp turns or obstructions), a quick flash of 60 flashes per minute is allowed.

The USCG aids to navigation light system requirements (Subpart 67.05) [41] for artificial islands and fixed structures are based on the size of the structure (e.g., obstruction). The minimum luminous intensities for flashing lights on obstructions which are greater than 15 m (50 ft) in diameter are not specified; however, a range of visibility of 1 nautical mile is required. For this large structure, the USCG also indicates that one light must be located at each corner, to be placed 90^o apart. The USCG also requires that when more than one obstruction light is required to mark a structure, all such lights shall be operated to flash in unison. The flashing lights must display a quick-flash characteristic of approximately 60 flashes per minute unless prescribed otherwise by the permit issued. Lights are required to operate from sunset to sunrise; during such times no other lights shall be exhibited except for lights that cannot be mistaken for the specified lights.

4.2.2 "Anti-Collision" Light Systems

The FRA requirements for steady burn and flashing light intensities for auxiliary external alerting lights are contained in the 1993 and 1994 Interim Rules, as summarized in Appendix A. Table 4-2 lists those requirements for steady burn and flashing light system components, respectively. Both of these alerting light systems are considered to be "anti-collision" light systems because they specifically permit an external observer to detect and thus avoid a hazard.

Table 4-2. FRA Requirements for Locomotive "Anti-Collision" Light Systems

ALERTING LIGHT SYSTEM	LUMINOUS INTENSITY	EFFECTIVE INTENSITY	FLASH RATE	ANGLE FROM CENTERLINE OF THE LOCOMOTIVE	RANGE OF VISIBILITY IN M (FT)
Crossing Lights	Two lights, each 200,000 candela	Two lights, flash alternately, no effective intensity specified	40 to 180 cpm	Within 15^o	None
Ditch Lights	Two lights, each 200,000 candela	Two lights, not applicable	Not applicable	Within 45^o	None
Strobe Lights	Not applicable	Two lights required, each 500 candela	40 to 180 cpm	None	None

The FRA Interim Rules require that the crossing light system installation include two lights, operated in a flashing mode, to be used in combination with the center-mounted headlight. Each crossing light is located towards the lower front sides of the locomotive. The railroads are permitted to operate the crossing light system in a steady burn or flashing mode; however, the allowable light focus angle from the centerline of the locomotive is different for the crossing light and the ditch light systems. This report uses the flashing mode of the crossing light system as the typical operation of this alerting light system.

The FRA Interim Rules require that the ditch light system consist of two lights, in a steady burn mode, to be used in combination with the center-mounted headlight. Each ditch light is typically located towards the lower front sides of the locomotive.

Both FRA Interim Rules require that the strobe light system installation use a pair of isotropic strobe lights which could be installed either near each front corner of the roof of the locomotive or on each front corner of the sill of the locomotive, and be operated in combination with the center-mounted headlight.

The use of multiple lights (point light sources), and vertical and horizontal spatial dimensions, as required in the

FRA May 1994 Interim Rule, provides a triangular pattern of three lights.

Subpart 25.1401 [44] of the FAA regulations requires that all airplanes be equipped with flashing anti-collision light systems. This system of flashing lights may consist of one or more lights located so that they do not impair the crew visibility or detract from the position light conspicuity. The light system must consist of enough lights to illuminate the vital areas around the airplane, considering the physical configuration and operational characteristics of the airplane. In addition, the effective intensity of each light must equal or exceed 400 candela at 0^{o} to 5^{o} longitudinal front centerline of the airplane. The system of flashing lights must give an effective flash frequency of not less than 40 cycles per minute (cpm), nor more than 100 cpm. In the case of overlapping flashing light sources, the frequencies may exceed 100, but not 180 cpm.

The FAA requirement for multiple lights to conform with specific physical configuration and operational characteristics of the airplane, allows for a consistent pattern of lights to be displayed.

The USCG requirements contained in 33 CFR, Subchapter D, Part 81 - 72 COLREGS (International Regulations for Preventing Collisions at Sea) require that the commercial maritime industry equip all vessels with anti-collision light systems [42]. Steady burn lights are specified as vessel anti-collision lights. The COLREGS minimum light intensities are shown in Table 4-3.

Table 4-3. USCG Marine Vessel Maximum Luminous Intensity for Anti-Collision Light Systems - Steady Burn

LUMINOUS INTENSITY (Candela)	RANGE OF VISIBILITY Nautical Mile (nm)
0.9 candela	1 nm
4.3 candela	2 nm
12 candela	3 nm
27 candela	4 nm
52 candela	5 nm
94 candela	6 nm

The COLREGS requirements also state that the maximum luminous intensity of "navigation" [*sic*] lights should be limited to avoid undue glare; a variable control of luminous intensity is not allowed.

The inland navigation rules contained in 33 CFR, Subchapter E-Annex I, Part 84 [43], are identical to the COLREGS.

4.2.3 Analysis

The analysis presented below is based on the transportation mode regulations for external alerting light systems that are applicable to vehicles or vessels comparable in size to locomotives. All three transportation modes (rail, air, and marine) use external light systems for two functional purposes:

- "Aids to navigation" for the vehicle or vessel operator, and

- "Anti-collision" light systems for detection of a hazard by an external observer.

All three modes of transportation have specific requirements for external alerting light systems which vary according to their purpose and the respective operational environment: "aids to navigation" and "anti-collision." For both functions, the FRA, FAA, and USCG requirements pertain to three specific properties: luminous and/or effective light intensity (and/or range of visibility); flash rate, if applicable; and angular displacement from centerline of the vehicle or vessel.

The FAA regulations for installation of navigation light systems require that no objectionable glare be visible to the pilot.

The FRA Interim Rules specify minimum luminous intensity requirements; however, a maximum intensity is not included.

The USCG regulations do not include minimum or maximum luminous intensity requirements for lights installed on aids to navigation; two flash rates are specified for different types of flashing lights. The USCG requires the location of two diagonally opposite obstruction lights on marine structures with a horizontal dimension of over 9.2 m (30 ft) on each side, as well as obstruction lights on each corner of structures greater than 15.3 m (50 ft). These requirements provide a standard multiple light pattern, which varies according to size but with a minimum of two lights.

In addition, when anti-collision light systems are required, the FAA and USCG both specify maximum intensities to minimize glare to the external observer.

As noted earlier, a steady burn light can produce excessive glare on the vehicle/vessel operator or external observer, depending on light intensity, observation angle, distance, etc. The FAA and USCG include provisions for maximum luminous intensity of external light systems when multiple light sources are used. In addition, the FAA provides a maximum luminous intensity for overlapping beams of a steady burn system. The USCG specifically states in its regulations that the maximum luminous intensity of a steady burn light system should be limited to avoid excessive glare.

Both the FAA position light systems and the USCG obstruction light systems specify a fraction of a percent of the luminous intensity and effective intensity established by the FRA for locomotive headlights and alerting lights. The USCG requires a flashing light system for its aids to navigation light system, while the FAA and FRA require a steady burn light system for this purpose. The different approach pertains to the relative motion of the navigational targets in each case and the background luminance within the respective environments. Both airplane pilots and locomotive engineers must observe objects in motion to be able to estimate the rate of approach, whereas the USCG requirement describes conditions for navigation about a stationary object where detectability of the light system is the crucial issue. This approach is also applicable for anti-collision light systems used by these three modes of transportation. The FAA and the FRA require flashing lights for this alerting light system to enhance detectability of an object, while the USCG requires a steady burn light system to enhance the marine vessel operator's perception of rate of approach to the object. Further discussions of detectability and rate of approach within a controlled railroad field test environment are discussed in Chapter 5.

An important issue that pertains to flashing lights is the flash rate. An excessive flash rate can adversely affect an observer. All three transportation modes reviewed provide very similar ranges for flash rates of a flashing light source. In addition, the FAA regulations provide a maximum effective flash frequency for overlapping flashing lights within a flashing light system.

The FAA and FRA minimum effective intensities for flashing light sources are relatively similar, i.e., 400 effective candela and 500 effective candela, respectively.

The USCG minimum light intensity requirements are more limited than those of either the FRA or FAA. The USCG specifies the same miminum intensities for both steady burn and flashing lights sources: 94 candela and 94 effective candela, respectively. The USCG decreases its minimum range of visibility requirements for obstruction lights based on the number of flashing lights required.

The final light system aspect reviewed is the use of multiple lights within the external flashing light systems, regardless of functional purposes. The FAA and USCG consider the physical configuration of the vessel and/or structure to determine the number of lights required; in addition, the FAA includes the airplane's operational characteristics.

The FRA 1994 Interim Rule requires the use of a three-light triangular pattern, which is consistent with the FAA and USCG requirements for multiple lights. The FRA includes vertical and horizontal spatial dimensional requirements for the locomotive lighting arrangement which depicts a triangular pattern. Since the railroad operational environment has limited degrees of freedom (i.e., forward and reverse train movement), this pattern provides a reference point for an external observer to detect a train and estimate its rate of approach to a grade crossing. Moreover, this pattern could enable the motorist to identify a moving object (vehicle) as an approaching train rather than a motor vehicle at a grade crossing.

4.3 ALERTING LIGHT SYSTEM COMPONENTS SELECTED FOR TESTS

The alerting light system components selected for laboratory tests were based on the results of the literature review (Chapter 3), and a survey of railroads to identify the current and planned usage of alerting lights on locomotives. Based on the survey, specific alerting light components were selected for tests as shown in Table 4-4.

As an observer/motorist reference point, the luminous intensity of a 12 volt Wagner automotive headlight measured by the Volpe Center at the USCG facility ranges from 25,000 candela (low beam activation) to 50,000 candela (high beam activation). See Section 4.4.

Table 4-4. Alerting Light Components Selected for Tests

MANUFACTURER	LIGHT TYPE	WATTAGE (W) VOLTAGE (V DC)
General Electric	PAR 56 Locomotive Headlight	200 W 30 V DC
General Electric	PAR 56 Locomotive Headlight	200 W 75 V DC
Whelen	Circular Lens Strobe	12 V DC
Whelen	360^{o} Strobe	30 V DC
Whelen	Rectangular Lens Strobe	30 V DC

4.3.1 <u>Steady Burn Lights</u>

Typical steady burn locomotive headlights are defined by wattage, style of headlamp, and voltage available.

Locomotive headlight wattage was determined to range between 200 and 350 watts.

The style definition of locomotive headlights uses the variable Parabolic Allumination Reflection (PAR). Styles are available in model numbers 36, 46, and 56. The most prevalent style number found in the survey was the PAR 56 locomotive headlight. Headlight voltages range between 30 and 75 volts. Figure 4-1 shows the 200 watt PAR 56 30 volt (DC) locomotive headlight tested.

Figure 4-1. 200-Watt PAR 56 30 V Locomotive Headlight

4.3.2 Strobe Lights

Three basic strobe light designs are used in the railroad industry: 1) the circular strobe (forward facing round lens); 2) the 360-degree rotating strobe (usually mounted on the rooftop of the locomotive); and 3) the rectangular strobe (forward facing lens). The strobe voltage range was found to be between 12 and 30 volts (DC). See Figures 4-2, 4-3, and 4-4.

Figure 4-2. 12 V (DC) Circular Strobe Light

Figure 4-3. 30 V (DC) 360° Strobe Light

Figure 4-4. 30 V (DC) Rectangular Strobe Light

4.4 ALERTING LIGHT COMPONENT LABORATORY TESTS

The standard approach developed by the National Institute of Standards and Technology (NIST), based on the Illuminating Engineers Society (IES) Guidelines, was used by the Volpe Center to test both steady burn and flashing light components [36].

4.4.1 Background

The USCG Research and Development Center in Groton, Connecticut assisted in the conduct of laboratory studies on steady burn and flashing locomotive alerting light components, including strobe light components. The USCG facility performs research in the area of signal light characterization using its laboratory facilities.
Recent USCG test reports included the characterization of strobe light flashtubes and the development of a method to calculate the effective intensity of these light systems (Thacker, and Mandler and Thacker) [45 and 46]. The formulas in these test reports were used in the laboratory tests to calculate the effective intensity of the selected strobe lights.

There are three factors associated with flashing light system components that the tests must measure: 1) instantaneous intensity, 2) flash duration, and 3) the assumed constant of illumination available to the observer's eye. These factors must be considered when computing the effective intensity of flashing light systems. The illumination constant, as prescribed by the IES, was used in these tests. A light that has a higher effective intensity will appear brighter to the observer than a light with a lower effective intensity, even if the light with the lower effective intensity has a higher peak intensity.

4.4.2 Test Conduct

Alerting light component tests were conducted in the USCG Research and Development Center's light tunnel. Each light component was mounted on a motorized table. The motor control unit was driven by computer and rotated the light source through a 60^{o} arc in both the vertical and horizontal plane independently, in 1^{o} increments.

After the light component was activated, the light source traveled down the light tunnel approximately 10.5 m (34 ft), and was then reflected by a mirror to a light sensor. The light sensor was exposed to the light source for 5 seconds for each measurement. These measurements provided the data necessary to calculate the horizontal and vertical intensities measured in candela as shown in Appendix C.

The strobe lights required additional measurements to determine flash pulse duration and frequency of the multi-flash cycles. For this test, another light sensor and a digital oscilloscope to store input data were used. These measurements provided the data necessary to calculate the pulse duration and multi-flash cycles.

4.5 ALERTING LIGHT COMPONENT TEST RESULTS

The results of the test data collected at the USCG Research and Development Center in November and December 1992 are presented in the following text. Steady burn light components used in crossing and ditch light systems, and flashing light components used in strobe light systems are discussed separately in the following sections of this chapter.

4.5.1 Steady Burn Lights

Table 4-5 lists the results of measurements collected for steady burn lights. All PAR 56 locomotive alerting light components tested meet the FRA requirement for a minimum luminous intensity of 200,000 candela.

Table 4-5. Steady Burn Locomotive Headlight Data

TYPE, WATTS, VOLTS AND MANUFACTURER	CANDELA
PAR 56, 200 W, 30 V General Electric	265,586
PAR 56, 200 W, 75 V General Electric	283,707
PAR 56, 200 W, 30 V General Electric	217,500*
PAR 56, 350 W, 75 V General Electric	251,335*

* These components were not tested at the USCG; intensity data were provided by Quest Corporation (see Appendix C).

4.5.2 Strobe Lights

Table 4-6 lists the data collected for the strobe light systems. Only one strobe light component meets the FRA requirement for effective intensity equal to 500 candela. However, all of the light components tested meet the FRA flash rate requirement range of 40 to 180 cpm.

4.6 FINDINGS

A flashing light is better at alerting an observer of the presence of an object or structure, but a steady burn light affords the observer the opportunity to fix her or his attention on a point source of light to determine the rate of approach of the train, vessel, or airplane.

Table 4-6. Strobe Light Data

LIGHT TYPE AND MANUFACTURER	EFFECTIVE CANDELA
12 V Circular Lens - Whelen	63.75
30 V 360^{o} - Whelen	73.05
30 V Rectangular Lens - Whelen	932.68

The FRA Interim Rules permit use of either steady burn or flashing alerting lights.

The FAA and USCG requirements for light systems are based on their intended purpose: "aids to navigation" (ability to estimate the rate of approach) or "anti-collision" (ability to detect the presence of a hazard). However, the FAA requires flashing lights for airplane anti-collision light systems whereas the USCG requires steady burn lights for marine vessel anti-collision light systems. The discrepancy pertains to the relative motion of the navigational targets in each case. It is necessary for operators of both airplanes and locomotives to observe objects in motion to be able to gauge the rate of approach, whereas the USCG requirement describes conditions for navigation about a stationary object where detectability of the light system is the crucial issue. This variance is also true for the anti-collision light systems for all three modes of transportation. Accordingly, the FAA and the FRA require flashing lights for this type of alerting light system to enhance object detectability while the USCG requires a steady burn light alerting system to enhance vessel operator perception of rate of approach.

Further discussion of detectability and rate of approach within a controlled field test environment is contained in Chapter 5.

Specific intensity and type of light systems specified for the three transportation modes varies according to their intended purpose: detection or rate of approach. The FRA minimum criteria for steady burn light systems and effective candela for flashing light systems greatly exceed the FAA and USCG requirements. Specific criteria for minimum and maximum light intensity, and for multiple light usage, may be desirable to reduce glare on the eyes of the nighttime observer.

The USCG also decreases its minimum range of visibility requirements, based on the number of flashing lights required for the light system.

The FAA and USCG recognize the importance of the physical configuration of the vessel and/or structure to determine the number of lights required; in addition, the FAA includes airplane operational characteristics.

The FRA requirement for the use of a three-light triangular pattern is consistent with the FAA and USCG requirements for multiple lights. This pattern provides a reference point for an external observer to detect a train and estimate its rate of approach to a grade crossing. Moreover, this pattern could enable the motorist to identify a moving object (vehicle) as an approaching train, rather than a motor vehicle at a grade crossing.

All tested alerting light components exceed FRA Interim Rule requirements for intensity, with the exception of two strobe light components. All alerting light components tested meet FRA requirements for flash rate, where applicable.

4.7 CONCLUSIONS

The following specific conclusions are presented for consideration by the FRA in its development of final regulations to improve locomotive conspicuity:

- Flash rates for all three modes of transportation alerting lights reviewed were consistent.
- Minimum or maximum intensities, and the number and focus angle of alerting light systems are important design considerations which can prevent excessive glare to motorists.
- Multiple lights, luminous and effective intensities, spatial dimensions, focus angle, and pattern, all contribute to increasing the visual signal provided to an outside observer.
- The pattern requirements contained in the 1994 FRA Interim Rule were found to be consistent with the FAA and the USCG requirements based on physical conditions and operational characteristics of the vehicles or vessels.
- Alerting light components are currently available which meet the FRA Interim Rule criteria for intensity and flash rate, if applicable.
- All tested alerting light components currently used by the railroad industry exceed FRA Interim Rule requirements for intensity, with the exception of two strobe light components.

5. CONTROLLED FIELD TESTS OF SELECTED ALERTING LIGHT SYSTEMS

To measure the relative effectiveness of selected locomotive alerting light systems, controlled field tests were conducted to assess the strobe, ditch, and crossing lights described in Chapters 3 and 4. In November 1993, two locomotives equipped with three experimental auxiliary alerting light systems were operated through a simulated highway-railroad grade crossing site located at the railway yard facility in Ft. Eustis, Virginia. The standard headlight served as the control for comparison against each of the three auxiliary alerting light systems. This chapter summarizes the methodology used for the field test conduct, discusses the results of the experimental trials, and presents findings and conclusions.

5.1 METHODOLOGY

Each type of alerting light system was evaluated to provide an indication of its relative effectiveness in enhancing locomotive conspicuity under both daylight and darkness conditions. The standard headlight was the control condition against which the other three experimental alerting light systems were tested. (Each type of experimental auxiliary alerting light was always operated in combination with the standard headlight.) Comparison of the three experimental alerting light systems, as well as the activation of the headlight alone under both daylight and darkness conditions, provided an indication of the relative effectiveness of these lights under the normal range of ambient lighting found in real-world driving conditions.

Alerting light system performance measures were: (1) the distance from the simulated grade crossing where the test observers detected the locomotive (detection distance), and (2) the time period judgment by the observers when the locomotive would arrive at the simulated grade crossing (arrival time).

Detection distance was measured by recording the moving locomotive's distance from the grade crossing when the observer (subject) first indicated seeing an approaching locomotive. Relative effectiveness rather than absolute effectiveness of the alerting light systems was measured because of the difficulty in controlling for the effect of motorist expectations. Expectations play a significant role in determining when a motorist may detect a train at the crossing. The average motor vehicle driver encounters a train infrequently and thus does not expect to see a train. Ziedman et al. states that motorists detect an unexpected target at half the distance that they detect an expected target [47].

Locomotive arrival time was measured by recording the observer's time estimate in seconds when the locomotive was either 22, 17, 12, or 7 seconds away from the crossing.

5.1.1 <u>Field Test Site</u>

The experimental trials were conducted at a field site located at the Ft. Eustis railroad yard. For control purposes, it was determined that the test site should possess the following characteristics:

- Little or no train and vehicular traffic volume;
- Straight track length of 1,220 m (4,000 ft) able to support a locomotive speed of 40 km/h (25 mph);
- Roadway perpendicular to the track (90^{o}) and positioned with at least 610 m (2,000 ft) of straight track on either side of the roadway;
- Unobstructed view of the track in both directions; and
- Background with street lights acting as visual clutter.

The observers were positioned on the west side of the track, facing east to minimize differences in light levels from the left and right of observers. The observers sat in chairs 62.5 m (205 ft) from the simulated grade crossing, spaced to allow each individual an unobstructed view of the tracks. Figure 5-1 shows the test site layout and a typical observer position at the test site.

The display for the visual monitoring task was located on a table 2 m (6.6 ft) in front of each observer. The starting position for each locomotive was 610 m (2,000 ft) from either side of the crossing. This enabled the locomotives to maintain a constant operating speed of 40 km/h (25 mph) by 457 m (1,500 ft) away from the grade crossing.

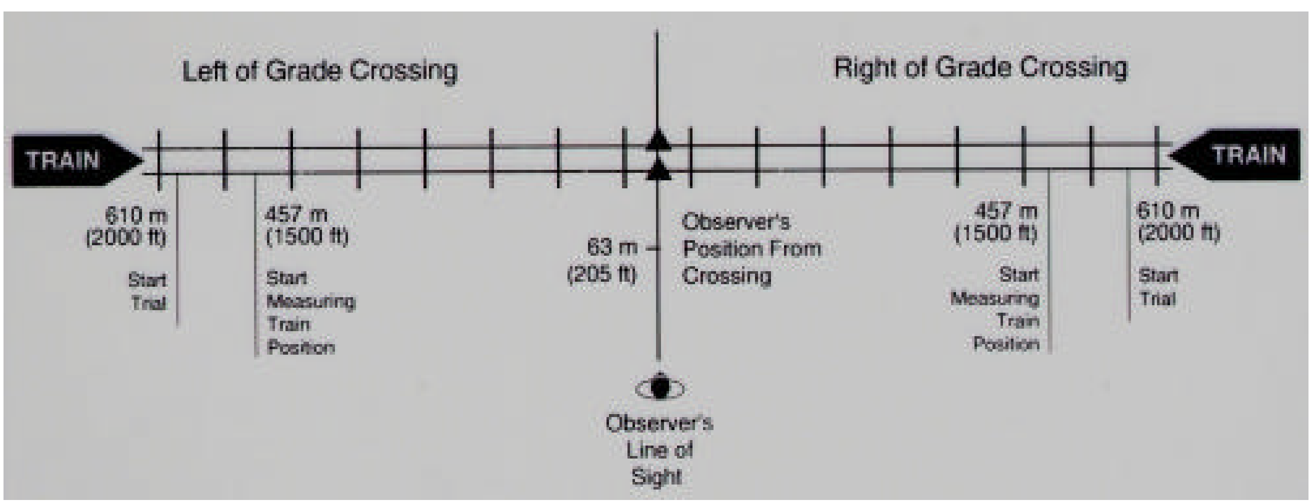

Figure 5-1. Field Test Site Layout and Observer Position

5.1.2 Locomotives and Experimental Alerting Light Systems

Two General Motors (EMD) GP-9 locomotives were each equipped with the standard headlight, as well as pairs of strobe, ditch, and crossing lights. The three experimental auxiliary alerting light systems complied with the applicable intensity, flash rate, and dimensional requirements contained in the FRA 1993 Interim Rule. The headlight and the alerting light systems were mounted on each locomotive in the positions shown in Figure 5-2.

Figure 5-2. Ft. Eustis Locomotives Equipped With External Experimental Alerting Light Systems

Both of the ditch lights (located on the outside corners) were pointed outward 15^{o}, while the angle of the crossing lights was 0^{o} from the centerline of the locomotive. The nose of one locomotive was painted red and yellow in a chevron pattern, the other was painted entirely red. The remainder of both locomotives were painted red. Appendix D contains more extensive information on the individual experimental alerting light specifications.

5.1.3 Observers

Twenty-eight observers were recruited for this experiment (one observer withdrew from the evaluation before it began) and were organized in groups of four. Data from the first group of four subjects was not collected due to equipment failure. Of the remaining observers, 13 were men and 10 were women who ranged in age from 21 to 75, with the mean age of 37. Each observer possessed a driver's license and a minimum visual acuity of 20/40 and were recruited from the local population (Ft. Eustis, VA); observers were each paid a minimum of $50 for their services, plus whatever they "won" from incentives from their participation in the experimental trials (see Appendix D).

5.1.4 Experimental Tasks

During each experimental trial, a group of observers performed three tasks: (1) a visual monitoring task, (2) a peripheral detection task, and (3) a train arrival time estimation task. Observers performed the visual monitoring task concurrently with the peripheral detection task, followed by the train arrival time estimation task. The visual monitoring task was used to represent the typical attentional demands on motorists in the real driving environment. Appendix D describes the incentive system established to maintain the observers' attention on the visual monitoring task.

At the start of each experimental trial, both locomotives were positioned at the starting position 610 m (2,000 ft) down the track, one to the observers' left and one to the observers' right. Only one locomotive from either side approached the simulated grade crossing in each trial. To minimize guessing, the alerting light system being tested was activated for both locomotives, and the direction of approach was randomized.

An experimenter at the observer station notified the experimenter in the locomotive cab by two-way radio when the trial started. For the visual monitoring task, seated observers monitored a visual display of an arrow 1.83 m (6 ft) in front of them, which took one of three possible forms: a two-headed arrow, a down arrow, or an up arrow. Figure 5-3 shows the size of the respective arrows.

The experimenter instructed the observers to monitor the visual display while their laptop computers recorded their responses to the visual monitoring task. An experimental trial began with the illumination of the two-headed arrow which changed intermittently to either an up or down arrow. When the computer displayed an up or down arrow, the observer was instructed to press the arrow key on the keyboard corresponding to the arrow displayed on the screen. Each of the observers wore headphones to eliminate auditory cues in detecting the locomotive's approach and direction.

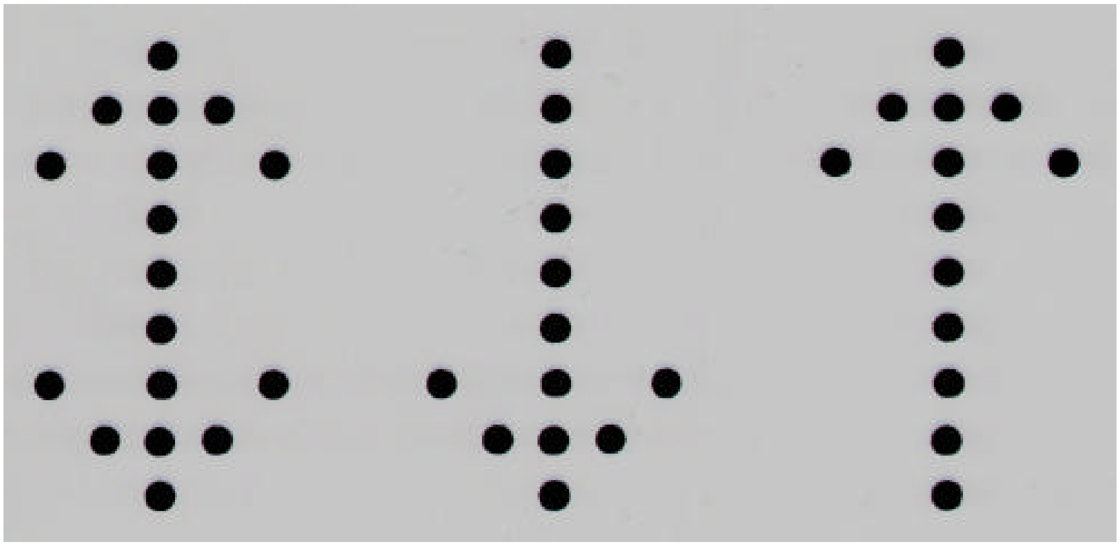

Figure 5-3. Laptop Computer Visual Display (Arrows Shown Actual Size)

Following a random 15-to-45 second delay from the start of the visual monitoring task, the alerting light system being evaluated for that trial was activated on both locomotives as one locomotive approached the simulated grade crossing. The other locomotive remained stationary.

The experimenter instructed each observer to avoid turning his or her head until an object was detected out of the corner of his or her eye. When the observer detected an object in peripheral vision, the observer could turn to view the object. If the observer determined that the object was a moving locomotive (motor vehicle movement occurred at random times on the road parallel to the track, unconnected with the experimental trials), the observer responded by immediately pressing the left or right arrow key on the computer, indicating the location of the locomotive. If the locomotive approached from the left, a correct response required pressing the left arrow key. The experimenter instructed observers to be consistent in their criterion for indicating when the moving locomotive was detected. When the observers detected the moving locomotive and recorded their responses on the laptop computers, the computers automatically recorded the distance at which the locomotive was detected.

At periodic intervals, an experimenter used a light meter to measure horizontal and vertical ambient light levels (illuminance) in lux (lx) as well as sky ambient light level (luminance) in footlamberts (fL), to account for changes in ambient light levels that might influence observer detection performance. No relationship was observed between ambient light level and the perceived brightness of any of the alerting lights.

After observers detected the locomotive, they were instructed to return to the visual monitoring task as quickly as possible and continue responding to changes in the visual display. Observers were asked to estimate the moving locomotive arrival time at the grade crossing by indicating when it was a specified interval from the crossing (i.e., 22, 17, 12, or 7 seconds). The specified interval was displayed on the laptop computer briefly at the start of the trial and again following the detection of the locomotive. When the observer estimated the locomotive to be at the appropriate interval, the observer responded by pressing the space bar on the keyboard. The trial ended when the locomotive arrived at the grade crossing as marked by two orange traffic cones.

5.1.5 Experimental Variables

The three independent variables in the experimental design were locomotive approach direction, ambient light level, and type of alerting light system (Table 5-1). Train speed was constant at 40 km/h (25 mph) which was important to minimize the effect of speed as a variable. For daytime and darkness light level situations, weather conditions allowed for visibility of at least 610 m (2,000 ft).

The experimental design was a mixed design with one between-subjects variable (ambient light) and two within-subjects variables (alerting light system and locomotive direction).

Half of the 28 observers were assigned to the daylight condition and half were assigned to the darkness condition. Within each ambient light level condition, each observer saw each alerting light system activation approach from both the left and right direction.

Each alerting light system activation was repeated 12 times for a total of 48 trials. Half of the trials were conducted under daylight conditions, while the other half were conducted under darkness conditions. For half the trials, the locomotive moved in one direction (i.e., from left to right, relative to the observer's position). For the other half, the locomotive moved in the opposite direction (i.e., from right to left, relative to the observer's position). The presentation order of the four alerting light systems was randomized.

Table 5-1. List of Independent Variables

LOCOMOTIVE APPROACH DIRECTION
Left Right
AMBIENT LIGHT LEVEL
Daylight Darkness
TYPE OF ALERTING LIGHT SYSTEM
Crossing Light Ditch Light Strobe Light Headlight Alone

5.2 RESULTS

The following two sections discuss the results of the controlled field tests of locomotives equipped with the experimental alerting light systems in terms of the ability of the observers to: (1) detect the approach of the locomotive and (2) correctly estimate its arrival time at the simulated grade crossing.

The effects of locomotive direction, ambient light, and type of alerting light system as they relate to locomotive detection distance and arrival time estimates are presented below.

5.2.1 Detectability

To measure the detectability of the experimental locomotive alerting light systems, detection distance served as the performance measure. Data from both the day and night experiments were analyzed together. To evaluate the detectability value of the four alerting light systems, a 2 x 4 x 2 mixed analysis of variance (ANOVA) was performed, where ambient light level condition (day/night) was the between-subject variable and the type of alerting light system and the direction of approach were the within-subject variables. Table 5-1 illustrates the 2 x 4 x 2 functions.

5.2.1.1 Effect of Locomotive Approach Direction

A main effect was found for locomotive approach direction ($F(1,21) = 15.01$, $p = .0009$).[1] This was an unexpected outcome as the approach of the locomotive from two directions was designed to control for the expectation that the observer knew a locomotive was approaching, rather than to test a hypothesis that predicted performance would vary by direction of approach. The mean detection distance was 425 m (1,394 ft) from the right and 367 m (1,202 ft) from the left, a difference of 59 m (192 ft).

The experimental alerting light system performance differences observed by individuals most likely relate to equipment failure on the locomotive approaching from the left. The generator that powered the alerting light system on the locomotive approaching from the left failed before the field evaluation began. Consequently, the alerting light systems operated using only battery power. However, the voltage was lower than the normal 74 volts required to operate the lights in revenue service (as low as 56 volts). Consequently, the light intensity for the alerting lights from the left was lower than on the right. The perceived brightness of the lights may have been lower, resulting in detection closer to the grade crossing. Appendix E illustrates how changes in voltage affect peak light intensity. Since only the locomotive approaching from the right side operated under conditions found in revenue service, the remaining discussion is limited to data from the locomotive approaching from the right.

5.2.1.2 Effects of Ambient Light

In comparing alerting light system performance between daylight and darkness, observers detected the locomotive at greater distances away from the grade crossing in darkness than in daylight ($F(1,21) = 7.68$, $p = .0115$). The mean detection distance was 468 m (1,560 ft) in darkness and 364 m (1,212 ft) in daylight, a difference of 104 m (348 ft). Among the statistically significant effects, ambient light condition accounts for the largest proportion of the variance (about 13%). Table 5-2 shows the detection distance for each alerting light system by ambient light condition. The

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[1] F stands for the F ratio. This value like other test statistics such as the T-test and post-hoc comparison tests (i.e., Tukey test and Student-Newman-Keuls test) represents the ratio of systematic errors plus unsystematic errors to unsystematic errors. The numerator includes the effects of the experimental treatment (e.g. alerting lights) plus the individual differences and measurement errors. The denominator includes everything found in the numerator <u>except</u> the effects of the experimental treatment. More specifically, the F ratio equals the mean square between subjects divided by the mean square within subjects. The more the F ratio rises above 1, the greater the likelihood the observed results were due to the result of the experimental effects being evaluated.

P stands for probability. The accompanying number represents the probability that the F ratio is due to chance. For example, $p = .01$ means that there is one chance in 100 that the observed result was due to chance.

greater detection distance for the darkness condition than the daylight condition suggests that the alerting light systems provided the stimulus by which the locomotive was detected. The painted surface of the locomotive facade was easily observable during the day; however, at night it was difficult to see when viewed head on and impossible to see when viewed peripherally. Under daylight conditions, most observers reported that the first thing they noticed was the lights, not the painted surface of the locomotive. These observations support the hypothesis that the experimental alerting light systems served as the means by which the locomotive was first detected. This outcome also implies that the experimental alerting light systems are not as attention-getting during the day as they are at night. The lower detection distance may be due to a variety of factors. One factor may be that there are other objects in the visual field competing for the observer's attention. During the day, when other objects are illuminated by the sun, a motorist may take additional time to discriminate moving objects like cars and trucks from the moving train. Another factor lies in the difference in brightness contrast between the alerting light system and the brightness of other objects in the visual field. Detectability is partly a function of the difference in

Table 5-2. Mean Detection Distance of Alerting Light System by Ambient Light Condition

ALERTING LIGHT SYSTEM	DETECTION DISTANCE M (FT)	
	Day	Night
Crossing Lights	405 (1349)	519 (1729)
Ditch Lights	355 (1183)	470 (1568)
Strobe Lights	361 (1203)	467 (1557)
Headlight Alone	333 (1109)	416 (1387)

brightness contrast between objects; the larger the difference in contrast, the easier it is for a person to detect an object. During daylight when the ambient light level is greatest, the relative contrast between light output observed from alerting light systems and other objects in a visual field is lower than at night, and motorists may take longer to detect them during the day.

5.2.1.3 Effects of Alerting Light System

Table 5-3 shows the mean detection distance by type of alerting light system. A statistically significant effect was found for alerting light system ($F(3,21) = 13.84$, $p < .0001$). This effect accounts for about 5% of the variance. The alerting light system (used in combination with the standard headlight) detected at the greatest distance away from the grade crossing was the crossing light, followed by respectively, the ditch and strobe light, and the headlight alone. Comparisons among the four alerting light

Table 5-3. Mean Detection Distance by Alerting Light System

ALERTING LIGHT SYSTEM	DETECTION DISTANCE M (FT)	TIME TO CROSSING AT 25 MPH (SEC)	VISUAL ANGLE AT DETECTION DISTANCE
Crossing Lights	464 (1548)	42.2	82.5°
Ditch Lights	417 (1391)	37.9	82.6°
Strobe Lights	413 (1377)	37.6	81.5°
Headlight Alone	377 (1257)	34.3	80.7°

systems show that the crossing light was statistically different from the ditch and strobe lights, and the standard headlight alone, while the ditch light was statistically different from the headlight alone ($CR_T(4,63) = 125.16$, $p < .05$).[2]

Comparison between the strobe light and the standard headlight alone is at the borderline of statistical significance depending on the choice of statistical test used to evaluate the pairwise comparisons. The choice of statistical test depends upon the experiment-wise error rate that the experimenter wants to tolerate in controlling for Type 1 error [48]. A Type 1 error occurs when the null hypothesis is true, but a person accepts the alternative hypothesis as true. For this analysis, the Tukey Studentized Range Test was selected to evaluate the pairwise comparisons because it is relatively conservative in controlling for Type 1 error. The strobe light was not found to be statistically significant from the standard headlight alone using the Tukey Studentized Range Test, but was found to be statistically different using a

[2] CR_T stands for the Tukey Studentized Range statistic. The critical range (CR) represents the difference that the two means must exceed to be considered statistically significant.

less conservative Newman-Keuls test (CR_{NK} (4,63) = 94.78, $p < .05$).[3] Given the history of the strobe light and its effectiveness as demonstrated in a variety of transportation modes (Aurelius and Korobow [28], Hopkins and Newfell [20], and Howett et al. [12]), it is reasonable to use the less conservative test and conclude that the strobe light is significantly different from the standard headlight.

All three experimental auxiliary alerting lights increased the conspicuity of the locomotive compared to the headlight alone. Observers detected the locomotive at greater distances away from the simulated grade crossing when any of the experimental auxiliary alerting lights was activated, than when the standard headlight alone was activated.

5.2.2 Arrival Time Estimation

To measure observer ability to estimate locomotive arrival time to the simulated grade crossing, subjects estimated when the locomotive was one of four intervals from the grade crossing (7, 12, 17, or 22 seconds). For example, if the observer estimated that the locomotive was 7 seconds from the grade crossing and the actual arrival time was 10.5 seconds, the observer underestimated arrival time, since the estimated arrival time was less than the actual arrival time. If the locomotive actual arrival time was 3.5 seconds, the observer overestimated arrival time, since the estimated arrival time was sooner than the actual arrival time. Underestimation gives the motorist more time than expected to make a decision to stop or continue through the grade crossing and thus a greater safety margin, in contrast to overestimation which provides the motorist less time than expected to make a decision.

The judgment accuracy of estimated locomotive arrival time served as the performance measure. To make judgments of different duration events comparable, the arrival time judgments were converted to percentage scores. An observer judging a 7-second interval that is actually a 10.5-second interval received a score of 50%. An observer judging a 7-second interval that is actually a 3.5-second interval received a score of 150%. A score under 100% meant that the observer underestimated the amount of time for the locomotive to reach the simulated grade crossing, while a score over 100% meant that the observer overestimated the locomotive's arrival at the crossing.

Data from both the daylight and darkness experiments were analyzed together. To evaluate the four alerting lights, a 2 x 4 x 2 mixed analysis of variance (ANOVA) was again performed, where ambient light condition (day/night) was the between-subjects factor and alerting light and direction of approach were the within-subject factors.

[3] CR_{NK} stands for the Newman-Keuls Studentized Range statistic. The critical range (CR) represents the difference that two

5.2.2.1 Effects of Locomotive Approach Direction

A statistically significant main effect was found for locomotive approach direction ($F(1,19) = 10.14$, $p < .05$). The mean arrival time judgment was 97.1% when the locomotive approached from the left and 108.1% when the locomotive approached from the right.

As noted in the train detection data section, this outcome was unexpected, since the direction variable was introduced to control for observer expectations that a locomotive was approaching the grade crossing on each trial. As also noted previously, the most likely explanation relates to the lower alerting light intensity levels on the left side locomotive approach compared to the right side. Accordingly, the following discussion is limited to data derived only from the right side approach locomotive.

5.2.2.2 Effects of Ambient Light

No differences were identified in observer ability to correctly estimate locomotive arrival time as a function of ambient light level.

5.2.2.3 Effects of Alerting Light System

There was a significant main effect for type of alerting light system ($F(3,57) = 4.90$, $p = .0042$). Table 5-4 shows how the mean of judgment of arrival time varied by the type of alerting light (used in combination with the standard headlight). An analysis of the pairwise comparisons shows that the ditch light system was statistically different from the strobe light system and the headlight alone; the crossing light system was statistically different from the headlight (CR_T (4,57) = 3.743, $p < .05$). Observers were less likely to overestimate arrival time when viewing the ditch and crossing light systems than when viewing the headlight alone.

Overestimation was smallest for the ditch light system, followed by the crossing and strobe light systems, and the headlight alone.

Overestimation was greatest for the headlight alone condition. From a safety perspective, underestimation of locomotive arrival time is better than overestimation, since underestimation results in the motorist having more time for action to avoid an accident.

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means must exceed to be considered statistically significant.

Table 5-4. Mean Arrival Time Judgment by Alerting Light System

ALERTING LIGHT SYSTEM	ARRIVAL TIME JUDGMENT (%)
Ditch Lights	101.5
Crossing Lights	04.7
Strobe Lights	08.1
Headlight Alone	117.9

Accuracy in estimating locomotive arrival time was measured by how close the judgment was to 100%; the smaller the judgment error, the more accurate the arrival time estimate. In terms of accuracy, observers exhibited the smallest judgment error for the ditch light system, followed by the crossing and strobe light systems. Judgment error was worst for the headlight alone. For the ditch, crossing, and strobe light systems, judgment error was not statistically significant. Only the locomotive arrival time estimates made for the headlight alone condition were statistically significant ($t(131) = 4.92$, $p < .05$).[4] A Bonferroni correction was applied to correct for inflation of the Type 1 error rate (Kleinbaum, Kupper, and Muller) [49]. While observers tended to overestimate how far the locomotive was from the grade crossing for all alerting light systems, the differences were statistically significant only for the headlight alone condition.

The arrival time data were also analyzed by time estimation interval to determine whether arrival time judgments were affected by the length of the time interval being estimated, and to determine whether arrival time judgments varied as a function of alerting light system by time interval. A significant effect was found for time estimation interval as well as an interaction between time estimation interval and alerting light system. As expected, arrival time judgments varied directly with the length of the time estimation interval being estimated ($F(3,63) = 16.3$, $p < .0001$). As the interval

[4] t stands for the t-value. Like the F ratio, the t-value represents a ratio of systematic errors to unsystematic errors. It measures the difference between two sample means divided by the standard deviation for the sample.

being estimated increased from 7 to 22 seconds, the judged arrival time went from underestimation to overestimation. At the 7-second interval, there was a tendency to underestimate the locomotive arrival at the grade crossing. At all other intervals, the judged arrival time was overestimated. As the estimated interval rose above 12 seconds, the percentage of overestimation grew with the increase in the estimated time interval. Table 5-5 shows the mean of arrival time judged as a function of time estimation interval.

Table 5-5. Mean Arrival Time Judgment by Time Estimation Interval

INTERVAL (SEC)	ARRIVAL TIME JUDGMENT (%)	DEGREES OF FREEDOM	T-VALUE	PROBABILITY
7	89.2	131	2.40	< .05
12	108.2	130	2.11	< .05
17	114.9	127	3.66	< .05
22	120.4	129	5.40	< .05

Examining the arrival time errors for each alerting light system by estimated time interval shows a more complicated picture. There was a statistically significant interaction between the alerting light system and the estimated time interval ($F(9,63) = 2.93$, $p = .0029$). Figure 5-4 shows how the arrival time judgments varied as a function of alerting light system and estimated time interval. Comparison of the arrival time judgments to a criterion of no errors in arrival time judgments (displayed as the horizontal line in the figure) indicates that the crossing light is the only alerting light system that shows no statistically significant differences from the no-error condition for all time estimation intervals.

The strobe light system shows the smallest error between 7 and 17 seconds, but beyond 17 seconds, performance falls off to a level that is statistically significant from the no-error condition (see Table 5-6). Both the ditch light system and the headlight alone

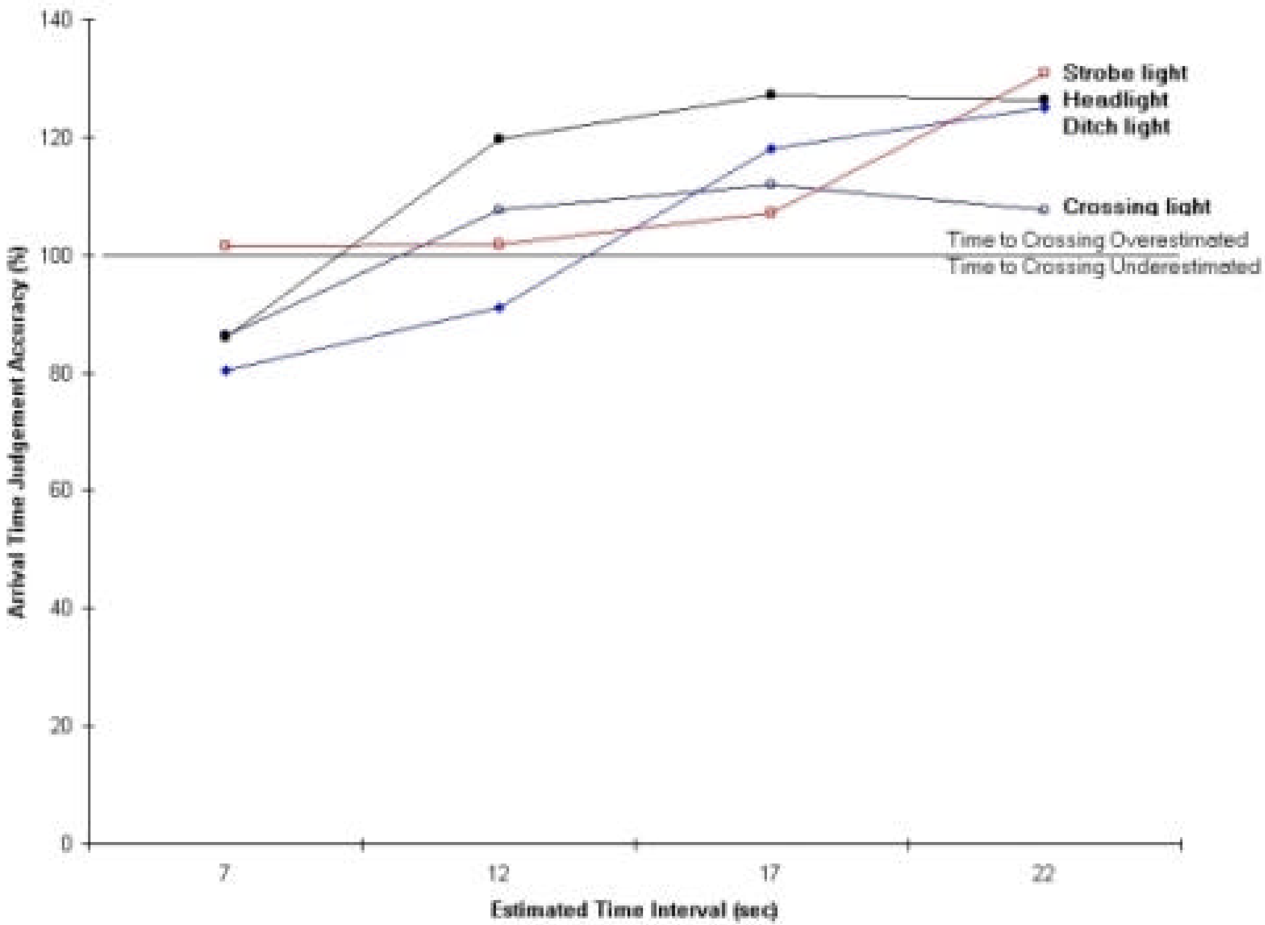

Figure 5-4. Effect of Alerting Light System on Mean Arrival Time by Estimated Time Interval

show a higher error magnitude at all four estimated time intervals, with the headlight exhibiting the greatest error. For the ditch light system, the differences are statistically significant at the 17- and 22-second intervals, as shown in Table 5-6. For the headlight alone conditions, the differences are statistically significant at the 12-, 17-, and 22-second intervals as shown in Table 5-6. For the strobe light system conditions, differences are statistically significant at the 22-second interval, as shown in Table 5-6.

In estimating the locomotive arrival at the simulated grade crossing, this analysis suggests that the accuracy with which observers estimate arrival time improves as the interval decreases below 12 seconds with a tendency toward underestimating arrival time. Above 12 seconds, there is a tendency to overestimate the time to arrival.

Table 5-6. T-Values for Alerting Light System by Time Interval

ALERTING LIGHT SYSTEM	INTERVAL (SEC)	ARRIVAL TIME JUDGMENT (%)	DEGREES OF FREEDOM	T-VALUE	PROBABILITY
Ditch	17	118	39	3.44	< .001
Ditch	22	125	23	3.48	< .002
Headlight	12	120	46	3.40	< .001
Headlight	17	127	22	3.97	< .001
Headlight	22	127	43	4.35	< .001
Strobe	22	131	19	3.73	< .001

The magnitude of the errors, in this case in the direction of overestimation, increases as the size of the time interval rises above 12 seconds. That is, the farther away the locomotive is detected, the greater the likelihood is that the motorist will overestimate how long it will take for the train to arrive at the crossing for 90^o grade crossings.

As noted previously, overestimation is more dangerous than underestimation because the motorist believes the train is farther away than it really is.

Observer overestimation of the locomotive arrival time at the simulated grade crossing was smaller for the three experimental auxiliary alerting light systems than for the standard headlight alone. Thus, usage of the standard headlight alone resulted in observer performance most likely to contribute toward an accident. Arrival time judgment was most accurate for the crossing light system, followed by the strobe and the ditch light systems.

5.3 FINDINGS

A number of findings relating to detectability and arrival time estimation as they relate to locomotive approach direction, ambient light level, and the effect of the experimental auxiliary alerting light systems are described and further discussed in this section.

Directional differences were found in the effectiveness of the alerting light systems for both detectability and arrival time estimation; however, the directional effects of the alerting light systems on detectability and arrival time estimation were attributed to equipment failure in one of the locomotives, resulting in lower alerting light system intensity on one of the locomotives.

5.3.1 Detectability

The greater detection distance for the darkness ambient light condition over the daylight condition suggests that all three of the experimental auxiliary alerting light systems (used in combination with the standard headlight) provided the stimulus by which the approaching locomotive was detected.

Observers detected the locomotive at greater distances away from the simulated highway-railroad grade crossing when any of the experimental auxiliary alerting light systems was activated, than when the standard headlight alone was activated.

The alerting light detected at the greatest distance away from the simulated grade crossing was the crossing light system, followed by the ditch and strobe light systems, respectively; the headlight alone was last. Both the crossing and ditch alerting light systems were detected by observers as far from, or farther away from the simulated grade crossing than the strobe light; this is significant, considering the results of previous studies (described in Chapter 3), which demonstrated the effectiveness of the strobe light and the higher intensity of the currently used strobe light. If the strobe light is the standard against which other alerting lights are measured, the crossing and ditch light systems tested in this study represent a considerable improvement over previous alerting light systems.

Because the individual experimental auxiliary alerting light systems share some properties and differ in others, it is difficult to determine what attributes contributed to their overall detectability. For example, both the strobe lights and crossing lights flash, though at different rates. However, the strobe light system was mounted on the roof and had a wide beam sweep, while the crossing light system was mounted much lower and had a narrow beam width directed parallel to the tracks. The ditch light system used the same type of headlamp as the crossing light system but did not flash, and was pointed 15^{o} away from the locomotive centerline. The parameters (e.g., position on locomotive, flash rate) that may promote or reduce conspicuity could not be separated in this analysis.

The locomotive was detected between 80^{o} and 83^{o} from the observer line of sight, as shown in Table 5-3. This angle is near the limits of observer ability to detect targets in peripheral vision. (However, the ability to detect the locomotive 80^o or more from the observer line of sight this frequently may not be typical of normal driver behavior.) Expecting that a train would approach on every trial, the observers may have looked directly down the tracks while engaged in the visual monitoring task. This "looking" behavior may occur with much lower frequency under normal driving conditions.

The absolute distances at which these experimental auxiliary alerting light systems would be detected under real-world conditions and the corresponding visual angle is likely to be closer to the observer line of sight than that observed in this controlled test. The actual distances at which the locomotive is detected may be up to half the distance observed in the trials, based upon an experiment conducted by Ziedman et al. [47].
While the three experimental auxiliary alerting light systems differed in relative detectability, it is not clear whether the results would be replicated under different conditions encountered by a motorist approaching an actual grade crossing. The controlled experimental trials examined the case where the grade crossing angle is 90^o and the observer is stationary and relatively close to the grade crossing (61.5 m [205 ft]).

A moving motorist may not detect the locomotive as well as the individual who is stationary. As distance from the alerting light systems increases, the detectability of alerting lights using the PAR 56 headlamp is likely to decrease because of the narrow beam width (3.5^o) of the lamp. As the observer moves out of the beam width of the lamp, the perceived intensity of the alerting light decreases, making it more difficult to detect.

Grade crossing angle also plays a critical role in determining the detectability of an alerting light which possesses a narrow beam width. The alerting light using a PAR 56 headlamp will be more effective when the motorist approaches the locomotive at a 90^o angle than when the motorist and locomotive approach the grade crossing from the same direction, parallel to each other (0^o).

In addition, although the experimental alerting light systems differed in the distance at which they were detected, it is possible they differ in other significant ways that may impact motorist performance. For example, several observers commented that the ditch light system blinded them for brief periods as the locomotive passed by. Although this analysis did not measure the potential effects of night vision impairment attributable to the alerting light systems, this type of alerting light system could introduce a problem, such as glare, where none existed before.

Finally, the typical motorist does not expect to encounter a train for every approach to a grade crossing, yet motorists detect an unexpected target at half the distance that they detect an expected target [47]. In the controlled field test, observers encountered the approach of a locomotive on every trial; the implication is that they adopted higher expectations of seeing a train than would be typical of real-world driving. These expectations may have affected their behavior, making it difficult to determine the actual distances at which these lights would be detected under real-world conditions.

5.3.2 Arrival Time Estimation

No differences were identified in observer ability to correctly estimate locomotive arrival time as a function of ambient light level.

Observers overestimated arrival time as the distance of the locomotive from the simulated grade crossing increased. However, all three experimental auxiliary alerting light systems increased the accuracy with which observers judged the locomotive arrival time to the grade crossing when compared to the headlight alone.

Observer overestimation of the locomotive arrival time at the grade crossing was smaller for the experimental auxiliary alerting light systems than for the standard headlight alone. This improved performance may be attributable to the quality of the information provided by the auxiliary alerting light systems when used in combination with the headlight.

The perception of approach speed is based upon the rate of change of vehicle size on the retina [50]. As a vehicle approaches, the angular size on the retina increases. At great distances, a vehicle appears as a point source. However, it is difficult to perceive changes in velocity of a point source because changes in angular size of a point source are minimal. A locomotive with a single headlight presents only a single light source, while a locomotive equipped with a pair of auxiliary alerting lights forms a visual triangle with the headlight. The larger changes in angular size provided by the three-point triangle make it easier to judge the relative velocity of the locomotive.

5.4 CONCLUSIONS

The results of the experimental trials indicate that all three of the experimental auxiliary alerting light systems increase locomotive detectability and provide additional information to motorists to assist them in estimating train arrival time.

5.4.1 Detectability

- Different observer performance during daylight and darkness ambient conditions suggest that the experimental alerting light systems provided the stimulus by which the approaching locomotive was detected.

- All three types of auxiliary alerting light systems (crossing, ditch, and strobe) tested in combination with the standard headlight increase detectability of the locomotive over use of the headlight alone.

- Detection was best with the crossing light system.

- Glare could be a significant factor of alerting light performance which could negatively affect motorists.

5.4.2 Arrival Time Estimation

- The level of ambient light had no affect on observer ability to accurately estimate the locomotive arrival time.

- Comparison of the arrival time judgments to a criterion of no errors in arrival time judgments indicated that the crossing light system provides the best overall performance over the range of time intervals.

6. RAILROAD IN-SERVICE TEST EVALUATION

To reduce railroad-highway grade crossing accidents, U.S. railroads have installed various types of auxiliary external alerting light systems. Strobe lights, rotating beacons, ditch and crossing lights, and oscillating lights are used, in addition to the conventional headlight, to make locomotives more visible to motorists.

This chapter describes the results of an FRA/Volpe Center cooperative activity conducted to evaluate railroad experience in the use of selected alerting light systems under actual revenue operating conditions. In-service operational data on alerting light installation costs, maintenance requirements, and operational concerns, as well as the potential influence of these alerting light systems on highway-railroad grade crossing accidents are presented.

6.1 RAILROAD IN-SERVICE TEST EVALUATION PROGRAM

While a previous FRA-sponsored data collection effort relating to strobe lights was documented in 1980 [7], current data reflecting nationwide use of recently developed auxiliary external alerting light systems had not been previously collected. Accordingly, an in-service railroad locomotive alerting light system test evaluation program was conducted to obtain data for capital (i.e., equipment and installation) costs, maintenance requirements, and operational concerns, as well as their potential influence on highway-railroad grade crossing accidents. This program provided the opportunity to evaluate selected alerting light systems installed on locomotives in both passenger and freight service under real-world operating conditions.

The in-service operational test evaluation was conducted with three participating railroads over a period of approximately three years. The alerting light system installed on the locomotives of all three railroads consisted of two crossing lights (used in combination with the standard headlight). CalTrain-Peninsula Corridor commuter service (CalTrain) and Consolidated Rail Corporation (Conrail) were provided with FRA funding to install crossing light systems. These two railroads were responsible for the actual installation and maintenance of the light systems as well as the collection of data regarding costs, maintenance, operational concerns, and accident statistics. Norfolk Southern Railroad conducted an independent test program of a crossing light system and provided data similar to CalTrain and Conrail. In addition, Burlington Northern Railroad supplied limited data on its use of a strobe light system and subsequent initial installation of a crossing light system.

Crossing light system locations on the railroad locomotives satisfied the horizontal and vertical dimensional requirements of the FRA 1993 Interim Rule.

6.2 CALTRAIN-PENINSULA CORRIDOR COMMUTER SERVICE

The CalTrain "Peninsula Corridor" commuter rail passenger service operates between San Francisco and San Jose, California. This commuter operation is a cooperative effort by the Peninsula Corridor Joint Powers Board which is comprised of the three counties through which CalTrain operates. Day-to-day operations are managed by Amtrak. The CalTrain railroad right-of-way runs north-south for about 77 km (47 mi), parallel to the heavily traveled California State Highway 101. There are 28 station stops along the route, about a 1 hour commute time from terminal to terminal. There are 56 highway-railroad grade crossings over the railroad right-of-way, some close to the entrance and exit ramps of the highway.

Current operations provide approximately 30 round trips per day. Including railroad operations from other carriers, there are about 48,300 km (30,000 mi) of rail operations a week along the peninsula corridor. All grade crossings are equipped with active warning devices (flashing lights and gates). Traffic signals are not preempted by railroad grade crossing control signals.

The CalTrain in-service test operation provided experience with high-density traffic and adverse visibility conditions caused by frequent and persistent fog. Since the corridor runs north-south, the sunrise provides a glare for motor vehicle drivers traveling eastward in the morning, and sunset provides a glare for motorists headed westward in the evening. There is commercial development all along the corridor which, along with highway overpasses, often obstructs the vision of motorists at grade crossings.

The "push-pull" operation of the trains provided single route experience with and without alerting lights, since only the locomotive-end of the train was equipped with a crossing light system.

6.2.1 <u>Alerting Light System</u>

CalTrain equipped its entire fleet of 20 commuter locomotives with crossing light systems which were installed beginning in March 1993. All locomotives were equipped with crossing lights as of October 19, 1993. Table 6-1 shows the number of locomotives operating with the crossing light system during the installation period.

Table 6-1. CalTrain Locomotives Equipped with Crossing Light System During Installation Time Period

INSTALLATION TIME PERIOD	LOCOMOTIVES EQUIPPED WITH CROSSING LIGHT SYSTEM
March 1993	1
June 1993	4
July 1993	10
August 1993	14
September 1993	18
October 1993	20

The crossing light system used two Apollolite II model XX-DLP-X light fixtures with PAR 56 350-watt, 75-volt bulbs. Figure 6-1 shows the head-end of a CalTrain locomotive equipped with the crossing light system. Figure 6-2 shows the cab-car end of a CalTrain train. Trains operating towards San Jose exhibit the crossing light system installed on the locomotive; trains operating towards San Francisco do not. In addition, the front ends of both the CalTrain locomotives and the cab-cars are marked with red and white stripes in a chevron pattern, using either paint or an adhesive-backed retroreflective material.

The crossing light system displays a steady-on aspect while the locomotive is being operated, except when the bell or horn is sounded. At that time, it displays an alternately flashing aspect for 30 seconds before returning to a steady-on state. In addition to the crossing lights, CalTrain locomotives operate with the standard headlight and an oscillating light (which are constantly on while the locomotive is moving).

6.2.2 Equipment and Installation Costs

Equipment costs for the crossing light system were approximately $1,000 per locomotive for the CalTrain fleet. Installation of the crossing light system cost an additional $1,200 per unit resulting in a total retrofit cost of about $2,200 per locomotive. Due to the passenger locomotive structure and style (lack of front walkway and handrail found on freight locomotives), installation required fabricating a mounting device, increasing slightly the installation costs over that expected for freight locomotives.

6.2.3 Maintenance Requirements

CalTrain indicated that maintenance requirements have been minimal since the only part susceptible to failure is the sealed beam bulb, a standard headlight lamp available in stock.

Figure 6-1. CalTrain Locomotive Equipped with Crossing Light System

Figure 6-2. CalTrain Train Cab-Car Not Equipped with Crossing Light System

6.2.4 Operational Concerns

Early in the test, CalTrain found it necessary to modify the use of the crossing light system by turning it off when another locomotive approached to avoid blinding the engineer of the oncoming train. This blinding effect resulted from the high intensity of the narrowly focused 350-watt PAR 56 light bulb. It is likely that this light would affect motorists approaching the locomotive head-on in a similar manner.

Two train engineers were interviewed about the effect of crossing light system use on their job performance. The train engineers had no strong opinions, either positive or negative, in this regard. The crossing lights automatically go from a "steady-on" state to flashing when the bell or horn is sounded at the approach of a highway-railroad grade crossing, so activating this function of the lights does not add to the workload of the engineer. Since the lights had to be turned off and on during the approach of an opposing locomotive, operation of the crossing light system added slightly to engineer workload. However, there were no complaints about this added task.

6.2.5 Accident Data

In the eight-month period between July 11, 1992 and March 2, 1993, prior to crossing light system installation on locomotives, a total of nine highway-railroad grade crossing accidents occurred on the CalTrain corridor test route. Six of these accidents involved trains headed by a locomotive, while the remaining three involved trains operating with the cab-car forward. Nine additional accidents occurred at locations other than grade crossings during this period.

The first CalTrain locomotive was equipped with the crossing light system on March 3, 1993. The crossing light system was installed on the remainder of the locomotives by October 19, 1993. During this eight-month transition period, seven grade crossing accidents occurred. Of this total, five trains were headed by locomotives (only one of which had a crossing light system installed at the time of the accident), and two trains were headed by cab-cars. Six other accidents occurred at locations other than grade crossings during this period.

From October 20, 1993 to July 25, 1994, only one grade crossing accident occurred; it involved a train headed by a cab-car. There were six non-grade crossing accidents during the same time period.

To obtain a more accurate measure of the potential influence of the crossing light system on accident rate, it is necessary to normalize the number of accidents by the level of train operations with and without use of the crossing light system. This allows a comparison of accidents on the basis of equal exposure levels of the public to these two conditions. With the data provided from CalTrain, it was possible to compute the number of months trains were operated with and without crossing lights. The normalized accident data was thus expressed as accidents per 1,000 unit-months.

Table 6-2 presents the CalTrain accident data for operations with and without the crossing light system expressed both in terms of the number of accidents (#ACC in Table 6-2) and normalized in terms of accidents per 1,000 unit-months (RATE) in Table 6-2. The accident experience on CalTrain is also shown in Table 6-2 for grade crossing accidents and non-grade crossing accidents. This table presents accident data for three approximately equal time periods. The first period of about 8 months is the time before any of the locomotives were equipped with the crossing light system. The next period of about 8 months is the time during which the systems were being installed. The final period of about 9 months is the time after all 20 locomotives were equipped.

As indicated in Table 6-2, there was a significant reduction in the rate of grade crossing accidents after crossing light system installation. The accident rate declined from 28 accidents per

Table 6-2. CalTrain Accident Data

Before Installation

GRADE CROSSING ACCIDENTS				OTHER ACCIDENTS				TOTAL ACCIDENTS			
WITH CROSSING LIGHTS		WITHOUT CROSSING LIGHTS		WITH CROSSING LIGHTS		WITHOUT CROSSING LIGHTS		WITH CROSSING LIGHTS		WITHOUT CROSSING LIGHTS	
#ACC	RATE*	#ACC	RATE	#ACC	RATE	#ACC	RATE	#ACC	RATE	#ACC	RATE
N/A	N/A	9	28	N/A	N/A	15	47	N/A	N/A	24	75

During Installation

GRADE CROSSING ACCIDENTS				OTHER ACCIDENTS				TOTAL ACCIDENTS			
WITH CROSSING LIGHTS		WITHOUT CROSSING LIGHTS		WITH CROSSING LIGHTS		WITHOUT CROSSING LIGHTS		WITH CROSSING LIGHTS		WITHOUT CROSSING LIGHTS	
#ACC	RATE	#ACC	RATE	#ACC	RATE	#ACC	RATE	#ACC	RATE	#ACC	RATE
1	14	6	24	1	14	7	28	2	29	13	52

After Installation

GRADE CROSSING ACCIDENTS				OTHER ACCIDENTS				TOTAL ACCIDENTS			
WITH CROSSING LIGHTS		WITHOUT CROSSING LIGHTS		WITH CROSSING LIGHTS		WITHOUT CROSSING LIGHTS		WITH CROSSING LIGHTS		WITHOUT CROSSING LIGHTS	
#ACC	RATE	#ACC	RATE	#ACC	RATE	#ACC	RATE	#ACC	RATE	#ACC	RATE
0	0	1	5	4	22	2	11	4	22	3	16

* Rate = Accidents/1000 unit-months

1,000 unit-months for the period prior to crossing light system installation, to 14 accidents per 1,000 unit-months for the period during crossing light system installation, to 0 accidents per 1,000 unit-months for the period after crossing light systems were installed on all locomotives. If the cumulative accident experience of locomotives equipped with crossing lights is considered for the entire 17-month period during and after installation of lights, the average accident rate is 6.6 accidents per 1,000 unit-months. Compared with the accident rate period prior to installation of any crossing lights (28 accidents per 1,000 unit-months), this accident experience represents a 76.4% reduction in the accident rate.

The reduction in accidents for the cab-car forward end of the train suggests that the crossing light system may be providing a secondary, beneficial "novelty" effect. The use of crossing lights may have increased the public's general awareness of train operations along the route. That is, the increased conspicuity of the crossing light-equipped locomotives may have led to increased motorist "looking behavior" at grade crossings which could then have reduced accidents for trains without crossing lights. An important contributing factor to the novelty effect is that CalTrain operates on a fixed route so that the public had frequent opportunities to be exposed to the "new" crossing light system. It is also noted that the number of non-grade crossing accidents declined as well both during and after the installation of the crossing lights. This implies that the addition of crossing lights may have also increased the awareness of pedestrians helping to reduce trespasser accidents. This increased awareness would have occurred even though the crossing lights do not flash in non-grade crossing situations. Unfortunately, any beneficial novelty effects of crossing light systems may be temporary. As motorists become familiar with crossing lights, their increased awareness at grade crossings and along the rail route could decline. Additional operational experience with the crossing light system would be necessary to more fully characterize the extent and duration of any novelty effect.

There may be other factors, uncontrolled for in the test, which also influenced the results. Such activities as increased enforcement, education, and public awareness programs could have contributed to accident reductions. Accordingly, the results, while positive, should be interpreted with some caution.

6.3 CONSOLIDATED RAIL CORPORATION

The Consolidated Rail Corporation (Conrail) operates on 27,951 km (17,368 mi) of track with 2,122 road locomotives, as of the second quarter of 1994. As of 1993, the Conrail system had 24,977 public and private highway-railroad grade crossings. Conrail operates trains in the Northeast and Midwest areas of the U.S. Road locomotives operate throughout the Conrail system.

6.3.1 Alerting Light System

Conrail uses a pair of crossing lights mounted at the front of the locomotive just above the level of the front platform (Figure 6-3). The lights are installed in fixtures on the front pilot sheet of each locomotive, just below the level of the walkway. The fixtures are mounted approximately 133 cm (52 in) above the top of rail and spaced approximately 136 cm (54 in) apart. Fixtures and lamps are aimed to project the light beam at a right angle to the front of the locomotive face, parallel to the track.

All installations are 350-watt, 75-volt sealed beam lamps using a Quest Apollolite II fixture. The flash rate for each light is 60 cycles per minute (cpm).

The crossing light system is turned on and off by the engineer independently of the headlight. If the crossing lights are not in use, they automatically illuminate and flash alternately whenever the horn is sounded.

Figure 6-3. Conrail Locomotive Equipped with Crossing Light System

As of December 31, 1994, 637 Conrail locomotives had been equipped with the crossing light system (389 retrofit and 257 new). All of these locomotives are in unrestricted service throughout the Conrail system. Many locomotives also travel onto other railroads as part of run-through agreements with those carriers. Conrail plans to equip all of its road locomotives with the crossing light system.

6.3.2 Equipment and Installation Costs

For the retrofit of locomotives, Conrail indicated that the crossing light system equipment costs were approximately $1,460 and the installation costs were $1,555.

6.3.3 Maintenance Requirements

Conrail spent approximately $135,300 on replacement parts in 1994. Components replaced were primarily comprised of controller units, brackets, and fixtures (usually damaged at grade crossings) and headlight lamps. During 1994 more than 1,500 lamps were replaced on the Conrail crossing light systems. (Replacement locomotive headlights are not included in this total.)

6.3.4 Operational Concerns

Conrail indicated that no operational concerns associated with the crossing light systems have been expressed by its locomotive engineers.

6.3.5 Accident Data

Highway-railroad grade crossing accident data was obtained for the Marion Branch and Dow Secondary lines between Goshen and Anderson, Indiana over a three-year time period. This segment of the Conrail system has 271 public and private grade crossings. During the first year of the test, 1992, this 179.1 km (111.3 mi) segment of track accounted for 33 grade crossing accidents, the highest number of accidents on any line segment of Conrail. Approximately 1,388 trains, none headed by locomotives equipped with the crossing light system, operated over this segment during that year. During 1993, Conrail started crossing light system installation on locomotives that operated over this segment. In 1993, 1,445 trains operated over the same segment. Of those trains, 343 were headed by locomotives equipped with the crossing light system. In 1993, there were 11 grade crossing accidents, only one of which occurred with a train led by a locomotive equipped with the crossing light system. In 1994, 629 trains without the crossing light system that operated over this segment experienced three grade crossing accidents. During the same period, 808 trains equipped with the crossing light system which operated over the same segment experienced six grade crossing accidents. These results are summarized in Table 6-3.

Table 6-3. Conrail Grade Crossing Accident Data

TEST PERIOD	NUMBER OF GRADE CROSSING ACCIDENTS		TRAIN OPERATIONS		ACCIDENT RATE (Accidents/ 1,000 Train-miles)	
	With Crossing Lights	Without Crossing Lights	With Crossing Lights	Without Crossing Lights	With Crossing Lights	Without Crossing Lights
Before Installation, 1992	NA	33	NA	1,388 Trains	NA	0.214
After Start of Installation, 1993	1	10	343 Trains	1,102 Trains	0.026	0.082
Further Installation, 1994	6	3	808 Trains	629 Trains	0.067	0.043

As with the CalTrain data, the Conrail data was normalized to account for the relative exposure of the public to trains with and without the crossing light systems. Because of the data available for Conrail, the normalization was done on the basis of train-miles instead of unit-months, as was the case with CalTrain.

Unfortunately, the information was not available to normalize the data in the same units. A comparison of grade crossing accident data for trains with the crossing light system to trains prior to installation of the system shows that the trains equipped with crossing lights had significantly lower accident rates. The rate of accidents per 1,000 train-miles for trains with the crossing light system varied between 0.026 and 0.067 which was 87.9% and 68.7% less, respectively, than the rate of 0.214 accidents per 1,000 train-miles for all trains on the same route prior to the crossing light system installation. If the cumulative grade crossing accident experience of locomotives with the crossing light system two-year period during light installation, the average accident rate is 0.055 accidents per 1,000 train-miles. This represents an average reduction of 74.3% compared to the accident rate of 0.214 grade crossing accidents per 1,000 train-miles prior to crossing light system installation.

The Conrail grade crossing accident rate is similar to CalTrain in that train accidents without the crossing light system also declined after crossing light installation had begun. For those trains without crossing lights, the accident rate declined from 0.214 to between 0.043 and 0.082 accidents per 1,000 train-miles. This represents a reduction of 79.9% and 61.7%, respectively. Again, as with CalTrain, the general reduction in grade crossing accidents may be due to the novelty of the crossing light system and may be temporary. In addition, this test was conducted over a fixed route, providing a greater opportunity for the public to become aware of the crossing lights, enhancing any novelty effect.

Since the grade crossing accident reduction even for trains without the crossing light system was so great, it is possible that other uncontrolled factors could have influenced results. Other measures such as improvements to grade crossing warning devices and barrier systems along the route, Operation Lifesaver programs, or other efforts aimed at public education or enforcement may have contributed to the accident reduction as well.

6.4 NORFOLK SOUTHERN RAILROAD

The Norfolk Southern Railroad (Norfolk Southern) operates on 23,662 km (14,703 mi) of track with 1,960 road locomotives, as of the second quarter of 1994. As of 1993, Norfolk Southern had 29,636 highway-railroad grade crossings. Norfolk Southern operates trains in the Southeast and South Central areas of the United States.

6.4.1 <u>Alerting Light System</u>

Norfolk Southern selected fifty GP60 locomotives (unit numbers 7101 to 7150) to be used in an independently conducted test of the crossing light system. Thirty of these locomotives had crossing light systems installed, while the remaining 20 did not. These locomotives were then operated throughout the Norfolk Southern system. Later, during further tests, the remaining 20 locomotives had crossing light systems installed. Figure 6-4 shows the Norfolk Southern locomotive equipped with the crossing light system.

The crossing light system consists of a pair of PAR 56 350-watt, 75-volt bulbs. The light housing is made by Translight and Mastra. The controller is made by Quest and Elkon.

The crossing light system was installed on the 30 locomotives during the period January 1, 1993 through June 30, 1993, as the units were sent into the shop for regular maintenance. During the period from April 30, 1993 to November 30, 1993, the crossing light system was installed on the remaining 20 locomotives.

(Note: Norfolk Southern also conducted a 9 month study using locomotive front ends equipped with either reflective logos or painted non-reflective decals [34]. (See Chapter 3, Section 3.6.2).

Figure 6-4. Norfolk Southern Locomotive Equipped with Crossing Light System

Two crossing lights were positioned on the front lead end of the locomotive 1.6 m (5.3 ft) apart on the front platform, 1.4 m to 1.5 m (4.5 to 6 ft) above the rail. The crossing lights were aimed 1^{o} inward and 2^{o} down so the right crossing light is aimed at the left rail and vice versa. The light beams converge at 107 m (350 ft) and reach the opposite rail at 213 m (700 ft).

A manual push button is located under the horn valve and, when depressed at any time by the train crew, it turns on the flashing aspect of the crossing light system for 30 seconds. A selector switch on the control stand activates the crossing lights continuously, either steady-on or flashing (for steady-on, headlights have to be on bright position and flashing lights have to be timed out). Activating the horn at any time automatically turns on the flashing aspect of the crossing light system for 30 seconds.

Norfolk Southern has indicated that as of December 31, 1994, 1,420 of its 1960 locomotives were equipped with the crossing light system; 1,012 bi-directional locomotives have crossing lights at both ends. Norfolk Southern plans to equip all remaining road locomotives and most switcher units with the crossing light system.

6.4.2 Equipment and Installation Costs

Norfolk Southern indicated that equipment costs were $1,500 and installation costs were $1,000 for the retrofit of each locomotive.

6.4.3 Maintenance Requirements

Norfolk Southern indicated that it experienced little problem relating to maintenance.

6.4.4 Operational Concerns

Norfolk Southern issued a bulletin that requires crossing lights to be dimmed when approaching and during mounting of the locomotive.

6.4.5 Accident Data

The highway-railroad grade crossing accident experience of the 50 Norfolk Southern locomotives was obtained for a one-year period prior to crossing light system installation on any locomotives, then for the 18-month period during and after crossing light system installation on 30 of the 50 locomotives, and then for an additional 8-month period during crossing light system installation on the remaining 20 locomotives. The grade crossing accident rate data are summarized in Table 6-4. The table presents the Norfolk Southern accident data for operations with and without the crossing light system, expressed both in terms of the number of accidents and normalized in terms of accidents per 1,000 unit-months. Table 6-4 presents accident data for three time periods. The first period of 12 months is the time before any of the locomotives were equipped with the crossing light system. The next 6-month period is the time during which the crossing light system was being installed on 30 of the locomotives. The next 10-month time span is the time period after all 30 locomotives were equipped with the crossing light system. The final 9-month period is when the remaining 20 locomotives were equipped with the crossing light system.

As indicated in Table 6-4, there was a significant reduction in the rate of grade crossing accidents for those locomotives equipped with the crossing light system. The accident rate declined from 105 accidents per 1,000 unit-months for the period prior to crossing light system installation, to 67 accidents per 1,000 unit-months for the period during crossing light system installation, to 60.4 accidents per 1,000 unit-months for the period after crossing light system installation, to 36.4 accidents per 1,000 unit-months for the period during which the remaining 20 locomotives were equipped with the crossing light system. If the cumulative accident experience of locomotives equipped with the crossing light system is considered for the entire 24-month period during and after light installation, the average grade crossing accident rate is 47.7 accidents per 1,000 unit-months.

Table 6-4. Norfolk Southern Grade Crossing Accident Data

TEST PERIOD	NUMBER OF GRADE CROSSING ACCIDENTS		LOCOMOTIVE UNIT-MONTHS		ACCIDENT RATE (Accidents/ 1,000 unit-months)	
	With Crossing Lights	Without Crossing Lights	With Crossing Lights	Without Crossing Lights	With Crossing Lights	Without Crossing Lights
Before Installation, 1/92-1/93	NA	63	0	600	NA	105
During Installation, 1/93-7/93	8	25	119	229	67	109
After Installation, 7/93-4/94	11	9	182	118.5	60.4	75.9
Further Installation, 4/94-12/94	15	8	412	135.5	36.4	59

Compared with the 105 accidents per 1,000 unit-months accident rate period (prior to any crossing light system installation), this result represents a 54.6% reduction in the grade crossing accident rate.

Grade crossing accidents for locomotives not equipped with the crossing light system declined slightly (17.2%) from a rate of 105 accidents per 1,000 unit-months to 86.9 accidents per 1,000 unit-months for the entire remaining 24-month period of the test, starting with the crossing light system installation. However, unlike the CalTrain and Conrail experience, the reduction in grade crossing accident rate for non-equipped locomotives was less significant. This outcome suggests that the novelty effect noticed with CalTrain and Conrail had a much lower influence on Norfolk Southern train operations. A possible explanation is that the Norfolk Southern locomotives equipped with the crossing light system were operated throughout the system and were not confined to a specific route. This operation may have reduced the frequency of exposure of the public to the new light design. Thus, the novelty effect may have been less, thus reducing the corresponding benefit of increased motorist looking behavior at grade crossings. Since the accident rate of locomotives without the crossing light system declined only 17.2%, this implies that the accident reduction for the crossing light-equipped locomotives was largely attributable to the crossing light system. This suggestion can be made with some confidence since both groups of locomotives were operated under similar conditions and any other factors that may have contributed to accident reduction would have affected the non-equipped group as well. However, there may have been some factors, uncontrolled for in the tests, which may have differentially affected one set of locomotives. Additional railroad operational experience will be necessary to validate the long-term effects of the crossing light system.

6.5 BURLINGTON NORTHERN RAILROAD

The Burlington Northern Railroad (Burlington Northern) operates on 46,570 km (28,937 mi) of track with 2,667 road locomotives, as of the second quarter of 1994. As of 1993, Burlington Northern had 31,961 public and private highway-railroad grade crossings. Road locomotives operate throughout the Burlington Northern system.

6.5.1 Alerting Light System

Burlington Northern originally used strobe lights as an alerting light system on about 25% of its locomotive fleet, rather than ditch or crossing lights. A total of 538 of these locomotives were equipped with the strobe light system. Two strobe lights are located on the walkway, approximately 1.4 to 1.5 m (4.5 to 5 ft) above the rail and are directed 15^{o} outbound from the locomotive centerline. The strobe light system uses xenon tube gas-fired strobes which run on 72 volts and are reflected outward with parabolic reflectors. The strobe light does not shine in a synchronous pattern; it is designed to draw attention to the train, but not to mesmerize the motorist. The strobe light system operates for approximately 20 to 30 seconds when the horn or whistle blows before the train enters a grade crossing. The strobe light system can also be started manually with a switch.

Burlington Northern has recently decided to use a crossing light system; all locomotives will be equipped with this type of alerting light system and the use of strobe lights will be discontinued. The Burlington Northern crossing light system operates in steady burn mode with the high-beam headlight until the horn or bell is sounded, the lights then go into a flashing mode. Burlington Northern has developed equipment using a laser to aim the lights so that the beams cross at 122 m (400 ft) and hit opposite rails at 244 m (800 ft) ahead of the locomotive.

6.5.2 Equipment and Installation Costs

Information was not available from Burlington Northern regarding equipment or installation costs for either strobe or crossing light systems.

6.5.3 Maintenance Requirements

Burlington Northern indicated that there were no particular maintenance problems with either the strobe or the crossing light systems.

6.5.4 Operational Concerns

Burlington Northern decided to change over to the crossing light system for consistency with neighboring railroads.

6.5.5 Accident Data

Burlington Northern did not provide any accident data pertaining to either the strobe or crossing light systems. Anecdotal comments collected from train crews indicated their belief that the strobe light system was effective in alerting motorists to the approach of a locomotive to the highway-railroad grade crossing. However, Burlington Northern did not compile statistical information which would permit an analysis of accident rate data for either strobe or crossing light system-equipped locomotives.

6.6 FINDINGS

A summary of the findings resulting from the limited railroad in-service test evaluation of crossing light systems is presented below. Because of the limited nature of the tests conducted, these findings should be viewed as preliminary.

6.6.1 Capital Costs

The capital (equipment and installation) costs of each of the crossing light systems tested have been estimated at approximately $2,600 per end of the locomotive. The costs include the installation of features necessary to limit locomotive engineer workload by interconnecting operation of the auxiliary alerting light system with activation of the audible warning device system.

6.6.2 Maintenance Requirements

All maintenance information collected to date has been anecdotal in nature. Due to the flashing nature of the crossing lights, their life expectancy may be reduced, requiring more frequent replacement of the bulb than with the standard headlight.

Since the ditch light system uses the same steady burn bulb as the standard headlight (and does not flash), it is expected to have a similar maintenance record.

Although the strobe light has a very long life cycle (no moving parts), it is not a standard replacement part.

6.6.3 Operational Concerns

The issue of glare has been identified as a safety concern. The train engineers of one railroad turns off the crossing light system when approaching opposing trains.

The standard locomotive headlight has a dimmer switch to compensate for excessive brightness, whereas all applications of the crossing light systems tested must be turned off either automatically (timed-out) or by the locomotive engineer. However, locomotive engineer workload will not be increased with the use of the crossing light system if the operation of the lights is automated in conjunction with the use of the headlight dimmer switch and the audible warning device system.

6.6.4 Accident Reduction Potential

Accident data were obtained from three participating railroads for time periods prior to, during, and after installation of crossing light systems on their locomotives. Analysis of grade crossing accident data provided by CalTrain and Norfolk Southern indicates a 76.4% and 54.6% accident reduction, respectively, after crossing light system installation; Conrail experienced a 74.3% grade crossing accident reduction (See Tables 6-5 and 6-6). Thus, for all three railroads, significant reductions in grade crossing accident rates were observed for locomotives equipped with a crossing light system, compared to those equipped with the standard headlight alone.

These results also show that the crossing light system may produce a secondary, beneficial effect of reducing grade crossing accidents for all train operations on the same routes, even for those locomotives that were not equipped with crossing lights. However, this novelty effect may be temporary and confined to those train operations where the public is exposed to the crossing light system frequently enough to increase their general awareness.

Table 6-5. Crossing Light System Accident Reductions - CalTrain and Norfolk Southern

LOCOMOTIVES	CALTRAIN ACCIDENT RATES (Accidents/ 1,000 unit-months)	NORFOLK SOUTHERN ACCIDENT RATES (Accidents/ 1,000 unit-months)
All Locomotives Prior to Installation of Crossing Light System	28	105
Locomotives Equipped with Crossing Light System	6.6	47.7
Reduction in Grade Crossing Accident Rate	76.4%	54.6%

Table 6-6. Crossing Light System Accident Reductions - Conrail

LOCOMOTIVES	ACCIDENT RATES (Accidents/1,000 train-miles)
All Locomotives Prior to Installation of Crossing Light System	0.214
Locomotives Equipped with Crossing Light System	0.055
Reduction in Grade Crossing Accident Rate	74.3%

To minimize glare, all locomotives operated by Norfolk Southern equipped with a crossing light system display a "cross-eyed" light beam focus angle, in combination with the flashing light aspect, when approaching a grade crossing.

None of the CalTrain or Conrail locomotives used the cross-eyed beam focus angle.

The railroad in-service test results, while positive, should be viewed with some caution since the data was too limited to provide a high level of statistical confidence. Other influences, unaccounted for in the study, such as educational and enforcement programs, may have also contributed to the grade crossing accident reductions.

6.7 CONCLUSIONS

The results of the railroad in-service test operational evaluation suggest that the use of the crossing light system on locomotives has the potential to reduce the rate of highway-railroad grade crossing accidents, with a minimum in capital costs, maintenance requirements, and operational concerns.

- Crossing light system capital costs were estimated at $2,600 per installation on the test locomotives.
- Crossing light system components require some additional maintenance due to the lower life expectancy of the incandescent light bulb when used in a flashing mode.
- Alerting light activation can be automated with tie-ins to other tasks of the locomotive engineer; therefore, workload impacts should be minimal.
- Reducing any glare impacts of the crossing light system to opposing locomotive engineers and motor vehicle drivers can be achieved by adjustable intensity and appropriate aiming of the light beam focus angle.
- In-service test accident statistics for three participating railroads show significant grade crossing accident reduction potential for locomotives equipped with the crossing light system, compared with those equipped with the standard headlight alone.
- The results of the in-service field tests, while positive, should be viewed with some caution since the data was too limited to yield a high level of statistical confidence.

7. OVERALL FINDINGS AND CONCLUSIONS

The Volpe Center study documented in this report evaluated a variety of external visual alerting devices, including several auxiliary light systems, paint schemes, and reflective materials.

7.1 SUMMARY OF FINDINGS

Although passive alerting devices (e.g., paint schemes and reflective material) can be used to enhance locomotive conspicuity, their effectiveness in alerting a motorist to a train approaching a highway-railroad grade crossing is limited. One factor is the focus angle (straight ahead) of the motor vehicle headlight which cannot typically illuminate a train approaching a grade crossing at an angle. Accordingly, the major focus of the Volpe Center study was directed at evaluating locomotive alerting light systems.

Three types of experimental auxiliary external alerting light systems: (1) crossing, (2) ditch, and (3) strobe (operated in combination with the standard locomotive headlight) were tested under controlled field conditions; the standard headlight alone served as a control. Crossing lights typically operate in a flashing mode, while ditch lights operate in a steady burn mode; focus angle may vary. All experimental alerting light systems were evaluated in terms of their effectiveness in improving the ability of the motorist to detect the approach of a train at a highway-railroad grade crossing and estimate its arrival time.

The results of the in-service railroad test operational experience for locomotives equipped with crossing light systems, were also evaluated in terms of capital costs, maintenance requirements, operational concerns, and potential accident reduction.

The findings of the study are summarized below in Table 7-1 and expressed as a relative ranking of the three selected auxiliary alerting light systems (used in combination with a standard locomotive headlight) against a set of evaluation criteria; the standard locomotive headlight alone was used as the baseline.

Table 7-1. Study Findings - Relative Ranking of External Alerting Light Systems

ALERTING LIGHT SYSTEM	MEETS FRA MINIMUM CONSPICUITY PERFORMANCE REQUIREMENTS			CONTROLLED FIELD TESTS		IN-SERVICE TEST OPERATIONAL EVALUATION			
	Intensity	Flash Rate	Pattern Design	Detection	Estimation	Capital Costs	Maintenance Requirements	Operational Concerns	Accident Reduction Potential
Crossing Lights	1	1	1	2	2	-1	-1	-1	2
Ditch Lights	1	N/A	1	1	1	-1	0	-1	**
Strobe Lights	1	1	1	1	1	-1	-1	-1	1
Headlight Alone	0	N/A	0	0	0	0	0	0	0

Meets FRA Conspicuity Minimum Requirements

Intensity - ability of alerting light to meet FRA Interim Rule performance criteria for intensity

Flash rate - ability of alerting light to meet FRA Interim Rule performance criteria for flash rate

Pattern - ability of alerting light system to meet FRA Interim Rule design criteria for triangular pattern

Controlled Field Test

Detection - ability of alerting light system to improve detection of locomotive

Estimation - ability of alerting light system to improve estimation of locomotive arrival time at the grade crossing

In-Service Test Operational Evaluation

Capital Costs - equipment and installation costs

Maintenance Required - level of maintenance required

Operational Concerns - operational impacts

Accident Reduction Potential- observed potential to reduce accidents

The following is the description of the evaluation criteria numerical scores:

2 = Best; 1 = Better; 0 = Standard headlight baseline; -1 = Worse; -2 = Worst; ** = No supporting data

The table provides a convenient means of integrating and presenting results of the study's multifaceted efforts. The evaluation criteria in Table 7-1 were placed into three groups that reflect the primary source of the information used to establish the rankings: (1) Meets FRA Minimum Conspicuity Requirements, (2) Controlled Field Tests, and (3) In-Service Test Operational Evaluation. A brief description of these evaluation areas and data sources is presented below.

7.1.1 Meets FRA Minimum Conspicuity Requirements

This evaluation area includes three evaluation criteria: Intensity, Flash Rate, and Pattern Design. These criteria were based on the minimum performance criteria as specified in the FRA Interim Rules published in 1993 and 1994. Laboratory tests were conducted to measure intensity and flash rate performance, if applicable, for alerting light components. All of the alerting light systems identified in the FRA Interim Rules were also evaluated in terms of their ability to promote a distinctive triangular light pattern.

7.1.1.1 Intensity

All of the steady burn alerting light components tested and currently used by the industry exceed FRA requirements for intensity. While only one strobe light tested met the FRA minimum effective intensity requirements, the other strobe lights are not widely used in the railroad industry. Therefore, all auxiliary alerting lights are ranked "Better" than the standard headlight alone. In addition, the alerting light intensities specified in the FRA Interim Rules are significantly higher than for other U.S. transportation modes, as well as those requirements specified in other international railroad transportation regulations. The vision of both motorists and engineers observing approaching trains could be impaired by the potential glare of high-intensity crossing and ditch alerting light systems.

7.1.1.2 Flash Rate

Neither the standard headlight (49 CFR, Part 225.125) nor ditch lights (FRA Interim Rules) are intended to be operated in a flashing mode. These lights were therefore rated as "Not Applicable." The crossing and strobe light systems were ranked as "Better" since they are both capable of meeting the minimum flash rate requirements of the FRA Interim Rule criteria. The FRA Interim Rule criteria for strobe and crossing light flash rates are consistent with the Federal Aviation Administration (FAA) and U.S. Coast Guard (USCG) alerting light system requirements.

7.1.1.3 Pattern Design

The ability of an alerting light system to create a distinctive uniform light pattern is important for enhancing motorist recognition of the approaching hazard as a train. This concept was adopted in the FRA 1994 Interim Rule and is also considered in the design requirements for traffic control devices at highway intersections.

The use of a pair of crossing, ditch, or strobe lights in combination with the standard headlight, permits these alerting light systems to meet the FRA triangular pattern specifications. The FRA pattern requirements are consistent with FAA and USCG regulations.

The use of either type of oscillating headlights, as described in the FRA Interim Rules, will not provide the FRA-specified triangular light pattern, unless used in combination with the crossing, ditch, or strobe lights.

7.1.2 Controlled Field Tests

This area includes two evaluation criteria: Detectability and Locomotive Arrival Time Estimation, obtained as a result of controlled field tests of selected alerting light systems conducted at Ft. Eustis, VA. The alerting light systems were tested under both day and night ambient conditions. Results of these tests analyzed observer performance in two ways: (1) peripheral detection of each light system, and (2) locomotive arrival time estimation at the simulated grade crossing.

Specific conditions under which the tests were performed include:

- a simulated 9O^{o} highway-railroad grade crossing;
- stationary individuals to observe the random approach of locomotives operated with crossing, ditch, or strobe light systems (used in combination with the standard headlight), in addition to operation of the headlight alone as control;
- locomotive approach from either direction; and
- a constant locomotive speed of 40 km/h (25 mph).

7.1.2.1 Train Detection

The results of the train detection test indicate that all three experimental alerting light systems increase the detectability of the locomotive, when compared to the standard headlight alone, as shown in Table 7-2.

The increase in detection distance provided by the crossing light system over that of the ditch light and strobe light systems, and the headlight alone was statistically significant. The increase in detection distance provided by the ditch light system was statistically significant only from the headlight alone. The comparison between the strobe light and the headlight alone is at the borderline of statistical significance and depends on the choice of statistical test used.

Given the extensive use of the strobe light and its effectiveness as demonstrated in a variety of transportation modes, the Volpe Center determined that, under the given test conditions, the strobe light system was statistically different from the headlight alone.

Table 7-2. Mean Detection Distance by Alerting Light System

ALERTING LIGHT SYSTEM	DETECTION DISTANCE METERS (FEET)	TIME TO CROSSING AT 25 MPH (SEC)	VISUAL ANGLE AT DETECTION DISTANCE
Crossing Lights	464 (1548)	42.2	82.5^{o}
Ditch Lights	417 (1391)	37.9	82.6^{o}
Strobe Lights	413 (1377)	37.6	81.5^{o}
Headlight Alone	377 (1257)	34.3	80.7^{o}

Previous FRA-sponsored studies concluded that the strobe light is a more effective alerting device than radial beacons, oscillating (Mars) lights, fluorescent panels, and roof-mounted incandescent lights. Therefore, ditch and crossing lights represent a considerable improvement over all previous external alerting devices, since both types of lights were detected at a greater distance away from the grade crossing than the strobe light.

The absolute distances at which the experimental auxiliary alerting light systems would be detected under real-world conditions and the corresponding visual angle are likely to be closer to the observer line of sight than that observed in the controlled field test. The actual distances at which the locomotive is detected may be up to half the distance observed in the trials, based upon an experiment conducted by Ziedman et al. [47].

Although the experimental alerting light systems differed in the distance at which they were detected, it is possible that they differ in other significant ways that may impact motorist response in a real-world driving situation. For example, several observers commented that the ditch light blinded them for brief periods as the locomotive approached. Since this controlled field test did not measure the potential effects of night vision impairment attributable to the alerting lights, it is unclear whether these lights will introduce a safety concern, such as motorist blinding, where none existed before. In addition, because the experimental auxiliary alerting lights differ in several attributes (e.g., position above top of rail, angular displacement from centerline of locomotive, type of lamp, flash rate), it is unclear which specific attributes contributed to the effectiveness of the individual alerting light systems.

7.1.2.2 Estimation of Locomotive Arrival Time

To measure the ability of a motorist to estimate the arrival time of the locomotive at a highway-railroad grade crossing, observers were asked to estimate when the approaching locomotive was at one of four time intervals from the grade crossing: 7, 12, 17, or 22 seconds. The results of the tests are presented in Figure 7-1. The estimates are expressed as a percent. The horizontal line on the figure at 100% represents no error.

The test results suggest that the accuracy with which observers estimate locomotive arrival time improves as the estimated interval decreases below 12 seconds. The results also show that, for locomotive arrival times greater than 12 seconds, there is a greater likelihood that the motorist will overestimate the arrival time at the grade crossing (percentage less than 100).

Overestimation is more dangerous than underestimation because the motorist believes the train is farther away than it actually is. Thus, overestimation can result in greater risk-taking behavior, increasing the potential for a collision. As shown in Figure 7-1, observer overestimation of locomotive arrival at the grade crossing was smaller for the three experimental alerting light systems than for the standard headlight alone. Thus, the display of the headlight alone resulted in observer performance most likely to contribute toward a collision.

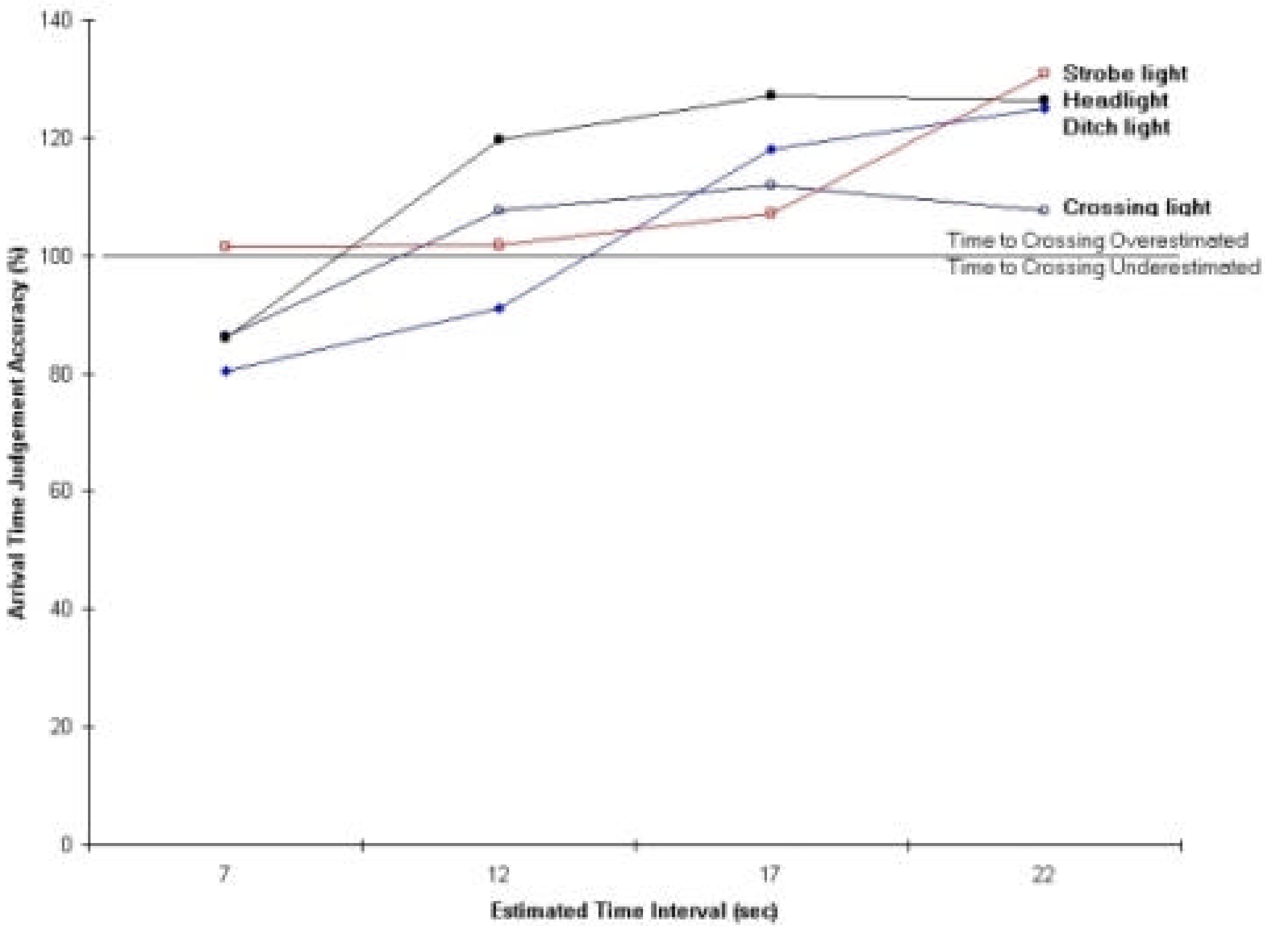

Figure 7-1. Effect of Alerting Light System on Mean Arrival Time by Estimated Time Interval

Comparison of the arrival time judgments to a criterion of no errors in arrival time judgments (displayed as the horizontal line in Figure 7-1) shows that the crossing light system provides the best overall performance. The crossing light is the only system that did not produce a statistically significant estimation error over the range of time intervals investigated. The strobe and the ditch light systems, while producing statistically significant errors at some time intervals, performed better overall than the standard headlight alone.

7.1.3 In-Service Test Operational Evaluation

This evaluation area includes four evaluation criteria: Capital Costs, Maintenance Requirements, Operational Concerns, and Accident Reduction Potential. These criteria were defined to reflect the results of the limited in-service test operational evaluation. These tests were conducted over a period of approximately two years. CalTrain, Conrail, Norfolk Southern, and Burlington Northern participated to varying degrees in this evaluation.

7.1.3.1 Capital Costs

The equipment and installation costs of each of the auxiliary external alerting light systems evaluated have been estimated at approximately $2,600 per end of the locomotive. The three alerting light systems have therefore been ranked as equal, but more expensive than the standard headlight alone since they represent an additional cost. The costs include the installation of features necessary to limit locomotive engineer workload by interconnecting operation of the alerting light system with activation of the audible warning device system.

7.1.3.2 Maintenance Requirements

The maintenance information collected to date has been limited. Due to the flashing nature of the incandescent bulb component within the crossing light system, bulb life expectancy may be reduced, requiring more frequent replacement than the standard headlight. Significant replacement over the standard headlight has not been documented to date, but crossing lights have been ranked slightly lower than the standard headlight because of this uncertainty. Since the ditch light uses the same lamp as the standard headlight (and does not flash), it is expected to have a similar maintenance record. The strobe light is not a standard replacement part and therefore has a lower ranking than the crossing or ditch light systems.

7.1.3.3 Operational Concerns

All three alerting light systems were ranked slightly worse than the standard headlight alone due to constraints in light system operation during the approach to a grade crossing or to an oncoming train. The aiming of the alerting lights between 15^{o} and 45^{o} outward from the locomotive centerline may cause glare on the approaching motorist. The train engineers of one railroad turn off the crossing light system when approaching opposing trains.

The standard headlight has a dimmer switch to compensate for brightness, whereas all applications of the auxiliary alerting light systems must be turned off either automatically (timed-out) or by the locomotive engineer. Interconnections with standard headlight and audible warning device switches will address these issues.

7.1.3.4 Accident Reduction Potential

Accident data were obtained from three participating railroads for time periods prior to, during, and after installation of crossing light systems on their locomotives. The data reflect crossing light system operating experience that ranged from nine months for Caltrain to three years for Norfolk Southern. Analysis of these data shows that, for all three railroads, significant reductions in grade crossing accident rates were observed for locomotives equipped with a crossing light system compared to those equipped only with the standard headlight. Results of the analysis are summarized in Tables 7-3 and 7-4. The results, while positive, should be viewed with some caution since the data were too limited to provide a high level of statistical confidence. Other influences, unaccounted for in the study, such as educational and enforcement programs, may have also contributed to the accident reductions.

7.2 CONCLUSIONS

The results of the Volpe Center study indicate that auxiliary external alerting light systems required by the FRA Interim Rules significantly improve locomotive conspicuity by providing additional information to assist motorists in: (1) detecting locomotives, (2) recognizing the train as a potential hazard, and (3) estimating train arrival time, thus reducing the potential for collisions at highway-railroad grade crossings.

Table 7-3. Crossing Light System Accident Reductions - CalTrain and Norfolk Southern

NUMBER OF LOCOMOTIVES	CALTRAIN ACCIDENT RATES (Accidents/ 1,000 unit-months)	NORFOLK SOUTHERN ACCIDENT RATES (Accidents/ 1,000 unit-months)
All Locomotives Prior to Installation of Crossing Lights	28	105
Locomotives Equipped with Crossing Lights	6.6	47.7
Reduction in Grade Crossing Accident Rate	76.4%	54.6%

Table 7-4. Crossing Light System Accident Reductions - Conrail

NUMBER OF LOCOMOTIVES	ACCIDENT RATES (Accidents/1,000 train-miles)
All Locomotives Prior to Installation of Crossing Lights	0.214
Locomotives Equipped with Crossing Lights	0.055
Reduction in Grade Crossing Accident Rate	74.3%

The following specific conclusions are presented for consideration by the FRA in its development of final regulations to improve locomotive conspicuity:

7.2.1 FRA Minimum Conspicuity Performance Requirements

- Alerting lights are currently available which meet the FRA Interim Rule criteria for intensity and flash rate, if applicable.
- Train approach speed, sight distances, ambient light conditions, and glare should be considered when specifying minimum and maximum levels for alerting light system luminous intensity and effective intensity.
- Crossing, ditch, or strobe light systems, used in combination with the standard headlight, provide a distinctive, uniform light pattern that can be recognized by motorists as signifying a locomotive.
- Use of either type of oscillating light alone, as described in the FRA Interim Rules, does not provide the FRA-specified triangular pattern.

7.2.2 Train Detectability and Arrival Time Estimation

- Each of the three experimental (crossing, ditch, and strobe) alerting light systems, used in combination with the standard headlight, increase detectability of the locomotive over the use of the headlight alone.
- Alerting light detection, under controlled field test conditions, was best with the crossing light system.
- Arrival time estimation performance, under controlled field test conditions, was best with the crossing light system.

7.2.3 Capital Costs

- The average alerting light system equipment and installation costs for the test locomotives were estimated to be $2,600 per end of locomotive.

7.2.4 Accident Reduction Potential

- In-service test accident statistics for three participating railroads show significant grade crossing accident reduction potential for locomotives equipped with the crossing light system, compared with those equipped with the standard headlight alone.
- The results of the in-service tests, while positive, should be viewed with some caution since the data was too limited to yield a high level of statistical confidence.

7.2.5 Other Considerations

- Passive alerting devices are considered to be of only limited effectiveness in improving locomotive conspicuity. Accordingly, these devices should be used only as a secondary technique to reduce collisions at highway-railroad grade crossings.

- Multiple lights, luminous and effective intensity, spatial dimensions, focus angle, and pattern all contribute to increasing the visual alerting signal provided to the motorist.

- The provision of an intensity control which supplies a lower luminous intensity level for the entire alerting light system, similar to the "dimmer" switch currently used for the standard headlight, would reduce the potential for glare.

- A "cross-eyed" alerting light beam pattern with lights angled inward and focused an extended distance down the track appears to have the positive features of a wider beam width and range in front of the train, as well as less potential for blinding motorists.

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APPENDIX A. SUMMARY OF FRA INTERIM RULES FOR AUXILIARY EXTERNAL ALERTING LIGHT SYSTEMS

ALERTING LIGHT SYSTEM	FRA INTERIM RULE #1 FEBRUARY 1993	FRA INTERIM RULE #2 MAY/AUGUST 1994	CHANGE
Ditch Lights	Two white lights; 200,000 candela Steady burn >60” apart; 36” to 84” inches above top of rail Focused horizontally within 45^0 of locomotive centerline Operational requirements: a minimum 20 seconds before reaching grade crossing and tied in with the operation of the bell and horn on the locomotive	Two white lights; 200,000 candela Steady burn 36” above top of rail or more 36” apart if vertical >60” 60” apart if vertical <60” Focused horizontally within 45^0 of locomotive centerline	Design dimensions changed based on triangular pattern Eliminated operational requirements
Strobe Lights	Two white stroboscopic lights >500 effective candela Flash rate 1.3 to 1.0 pulses/second >60” apart; >36” inches above top of rail Operational requirements: a minimum 20 seconds before reaching grade crossing and tied in with the operation of the bell and horn on the locomotive	Two white stroboscopic lights >500 effective candela Flash rate 40 to 180 flashes/min 48” apart or more 36” above top of rail or less	Flash rate expanded up to 180 flashes/min Design dimensions changed based on triangular pattern Eliminated operational requirements
Crossing Lights	Two white lights; 200,000 candela Steady burn or alternately flashing >60” apart; >48” inches above top of rail Flash rate 1.3 to 1.0 pulses/second Focused horizontally within 15^0 of locomotive centerline Operational requirements: a minimum 20 seconds before reaching grade crossing and tied in with the operation of the bell and horn on the locomotive	Two white lights; 200,000 candela Steady burn or alternately flashing If flashing, 40< flash rate <180 36” above top of rail or more 36” apart if vertical >60” 60” apart if vertical <60” Focused horizontally within 15^0 of locomotive centerline	Flash rate expanded up to 180 flashes/min Design dimensions changed based on triangular pattern Eliminated operational requirements
Oscillating Lights	One white light; 200,000 candela Steady burn - circle or figure-8 beam pattern Operational Requirements: a minimum 20 seconds before reaching grade crossing and tied in with the operation of the bell and horn on the locomotive	One white light; 200,000 candela Steady burn Two or more white lights - Steady burn Circle or figure-8 beam pattern 200,000 C each Focused horizontally within 5^0 of either side of locomotive centerline	Includes two or more lights but only at one location Specified focus of light Eliminated operational requirements

APPENDIX B. GRADE CROSSING CONFIGURATION ANGLES

B-1. GRADE CROSSING AT RIGHT ANGLES

Probably the easiest grade crossing for the visual aspect for the motor vehicle operator is the right-angle grade crossing as shown in Figure B-1. Here, as the motor vehicle approaches the crossing, the driver is afforded a good view in both directions of the tracks without turning the neck excessively unless there are obstructions.

B-2. GRADE CROSSING AT AN OBTUSE ANGLE

The motor vehicle driver who approaches a grade crossing at an obtuse angle (Figure B-2) has a fairly good visual aspect of a locomotive approaching from the right-front quadrant. For the motorist, the visual aspect in the right-front quadrant is better in that direction than in either direction of the right-angle

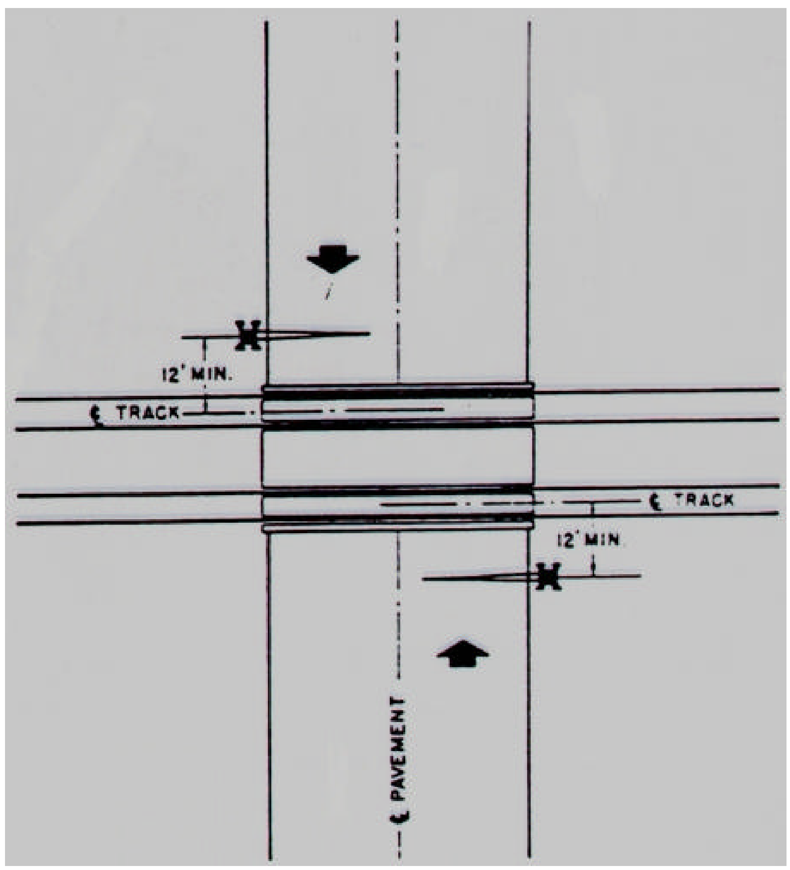


Figure B-1. Grade Crossing at a Right Angle to Roadway

crossing. To detect and recognize a locomotive from the other direction, the situation becomes considerably worse. Looking for a locomotive approaching on the tracks from the left-rear quadrant, however, requires the operator to look back somewhat over the left shoulder which takes the operator's eyes completely off the road in front, and can be somewhat painful for some people. If the motor vehicle is still moving forward, it can be quite a dangerous task. Assuming a straight highway, and a straight railroad right-of-way, Figure B-2 shows an obtuse angle for the motor vehicle driver traveling in either direction.

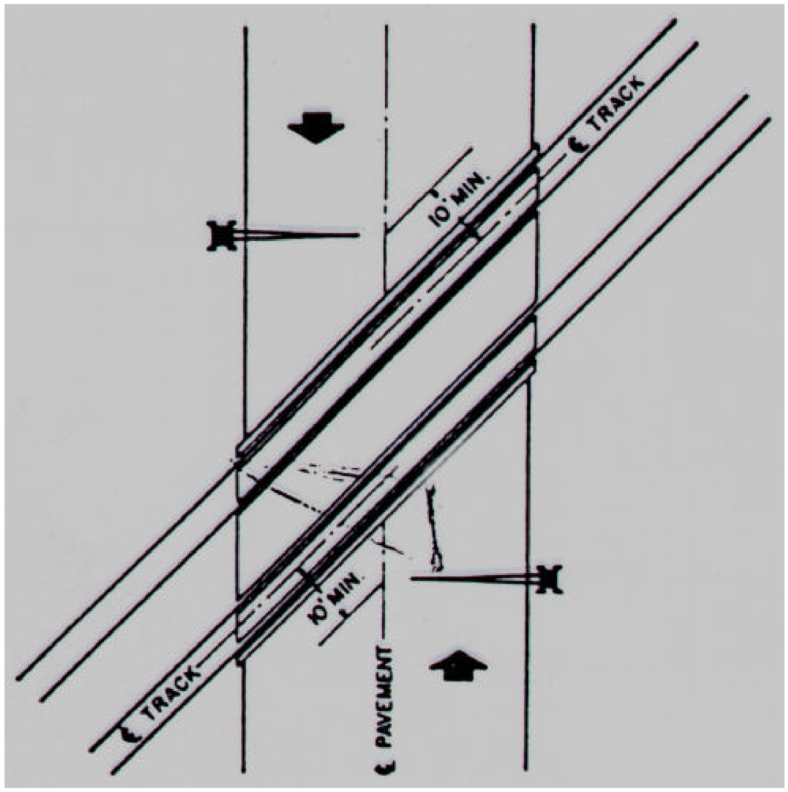


Figure B-2. Grade Crossing at an Obtuse Angle to Roadway

B-3. GRADE CROSSING AT AN ACUTE ANGLE

To the observer, the visual aspect for the motor vehicle driver approaching a grade crossing at an acute angle might seem to be the same as for the obtuse grade crossing. It is similar, but for locomotive conspicuity, it fares much worse. The motor vehicle driver who approaches a grade crossing at an acute angle as shown in Figure B-3, has a fairly good visual aspect of a locomotive approaching from the left-front quadrant. As in the obtuse grade crossing, the visual aspect in the left-front quadrant is better in that direction than in either direction of the right-angle crossing. For detecting and watching a locomotive approaching from the right-rear, the situation becomes far worse. Looking for a locomotive approaching on the tracks from the right-rear quadrant, however, requires the motorist to look back somewhat over the right shoulder which again takes the motorist's eyes completely off the road in front, and can be somewhat painful for some people. In almost every right-rear visual aspect (except for a motorcycle), the motorist has blind spots in his or her vehicle, if not total obstruction in looking in that quadrant. Again, if the motor vehicle is still moving forward, looking for a locomotive approaching from the right-rear can be a dangerous task. As described above for the obtuse angle, assuming a straight highway, and a straight railroad right-of-way, Figure B-3 shows an acute angle for the motor vehicle operator traveling in either direction on the highway.

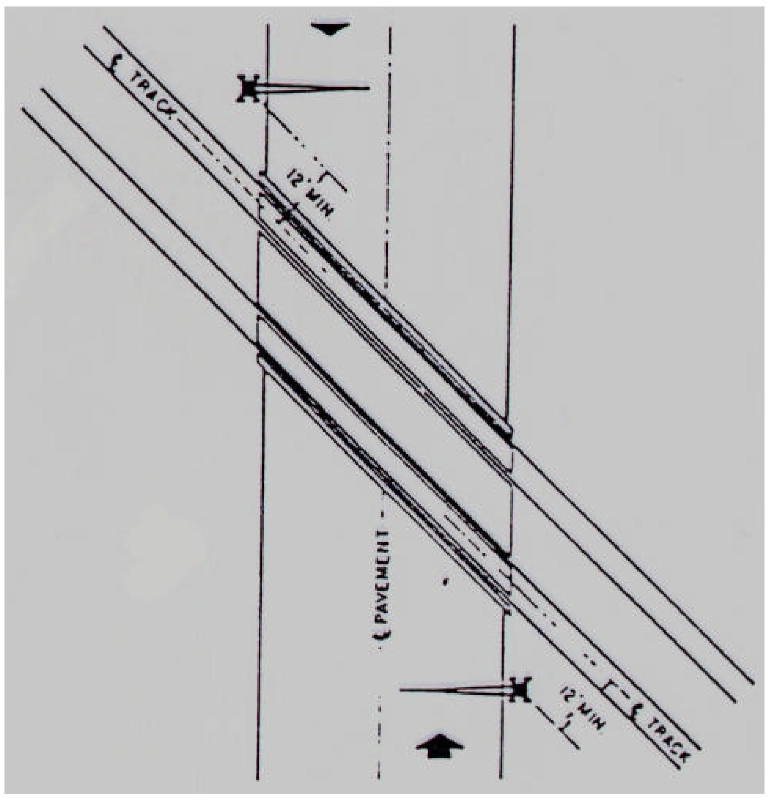


Figure B-3. Grade Crossing at an Acute Angle to Roadway

APPENDIX C. ALERTING LIGHT COMPONENT ISO-INTENSITY CONTOUR PLOTS

PLOT OF
ISO-INTENSITY CONTOURS

LANTERN = 30 V HEADLAMP
LAMP = GENERAL ELECTRIC 30.0 VDC, 6.85 A MEAS.
SOURCE TO DETECTOR DISTANCE = 34.46 FT (120 M)
DATE = 18 NOV 1992
OPERATOR IS BRIAN PICKETT

MAXIMUM VALUE IS 265586.454645
MINIMUM VALUE IS 65823.4510491

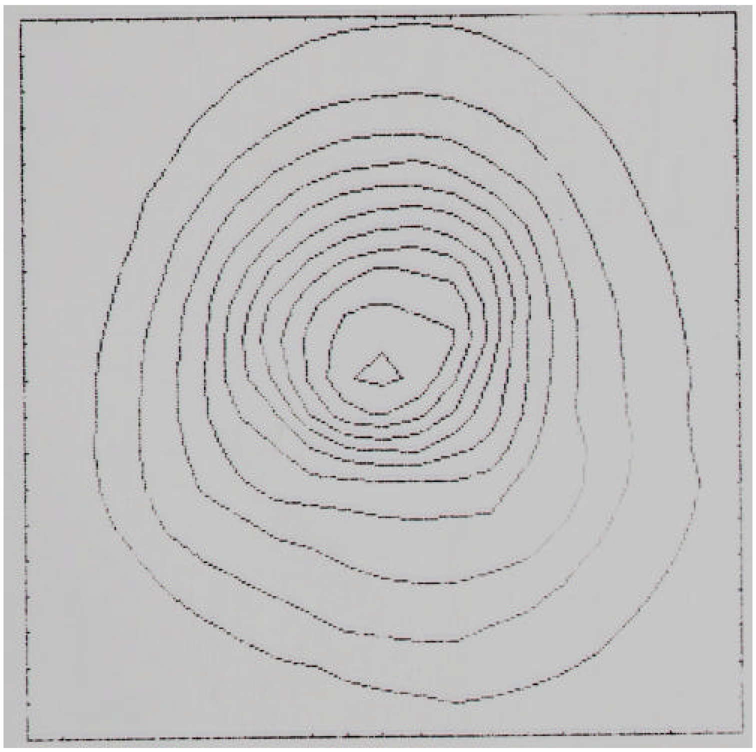
HORIZONTAL - -2.5 TO 2.5 DEGREES VERTICAL - 2.5 TO 2.5 DEGREES
MINIMUM: 65000 MAXIMUM: 265000 CONTOUR INTERVAL: 10000

Source: USCG

PLOT OF
ISO-INTENSITY CONTOURS

LANTERN = 75 V HEADLAMP
LAMP = GENERAL ELECTRIC 75.0 VDC, 5.00 A MEAS.
SOURCE TO DETECTOR DISTANCE = 34.46 FT (120 M)
DATE = 18 NOV 1992
OPERATOR IS BRIAN PICKETT

MAXIMUM VALUE IS 283707.576461
MINIMUM VALUE IS 1775.57702337



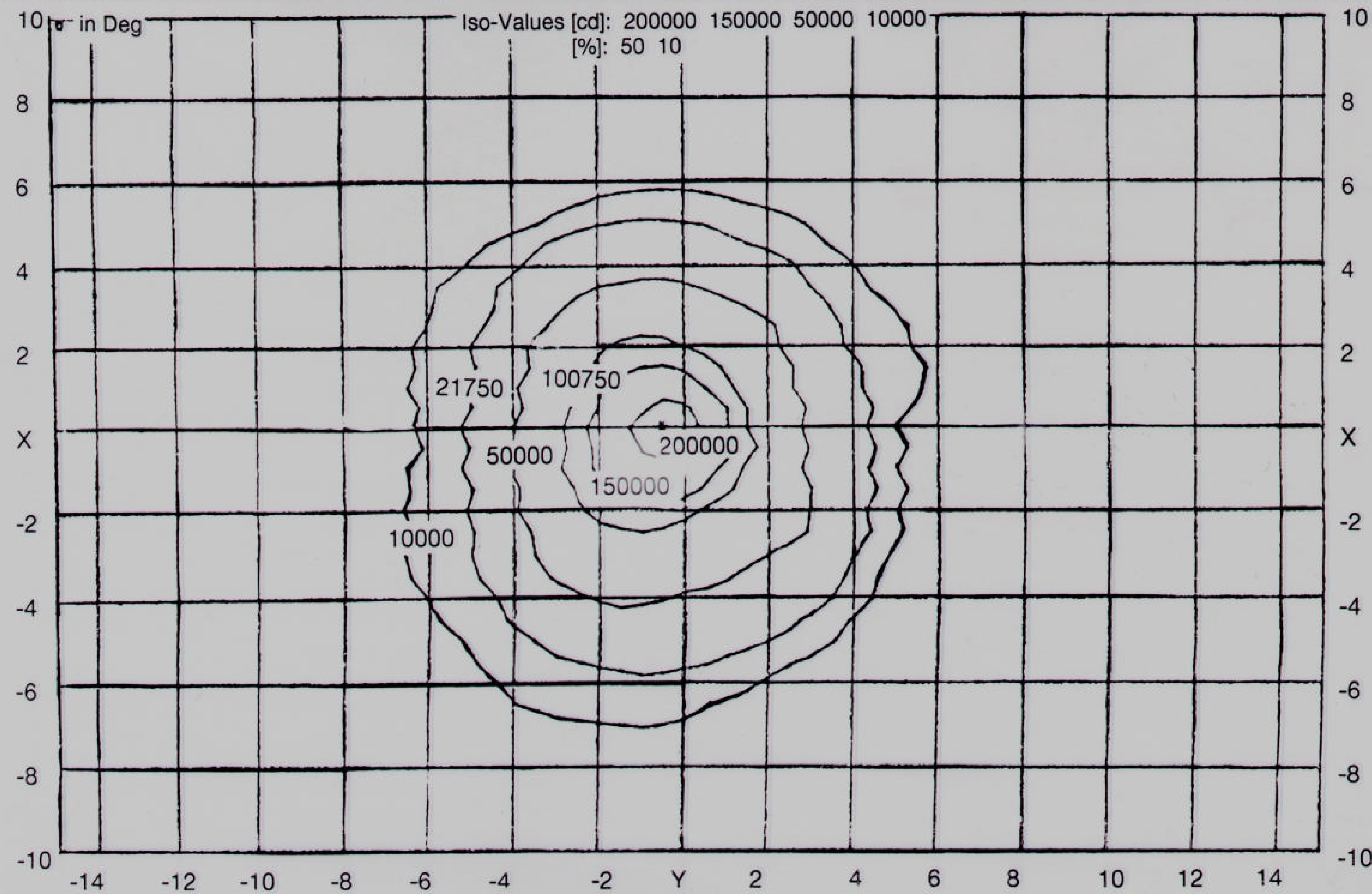
HORIZONTAL - -2.5 TO 7.5 DEGREES VERTICAL - 7.5 TO 7.5 DEGREES
MINIMUM: 1700 MAXIMUM: 280000 CONTOUR INTERVAL: 25000

Source: USCG

General Electric Company
Nola Park
Cleveland, Ohio

ISOCANDELA DIAGRAM

Type:	200W/PAR56	Imax:	217500cd
No.:	LOCOMOTIVE HEADLAMP	X:	-.50°
Report:	E91-7169	Y:	0.00°
Voltage:	30V		
Current:	6.730 A	File:	E7169_1



Source: Quest Corporation

General Electric Company
Nola Park
Cleveland, Ohio

ISOCANDELA DIAGRAM

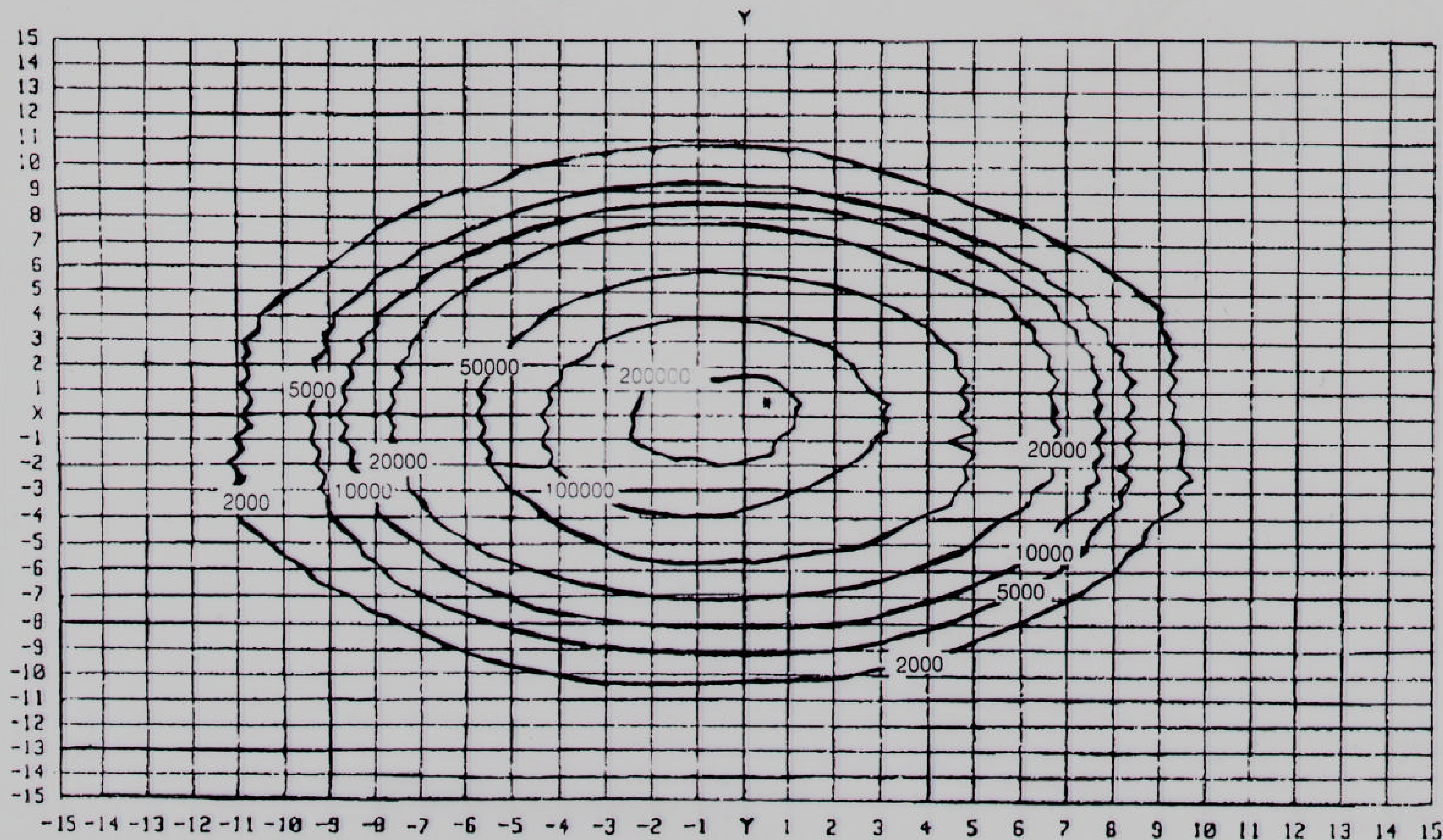
Type: LOCOMOTIVE
No.: 350 PAR56 75 VOLT
Report:

Imax: 251335cd
X: .50°
Y: .50°

File: 350PAR561

MaBstab in Grad

Iso-Horte [cd]: 200000 180000 50000 20000 18000 5000 2000



Source: Quest Corporation

APPENDIX D. CONTROLLED FIELD TESTS-SUPPLEMENTARY INFORMATION

D.1 OBSERVERS

Twenty-eight observers were recruited for the controlled field test conducted at the Ft. Eustis, Virginia railroad yard (one observer withdrew from the evaluation before it began). Data from the first group of four observers was not collected due to equipment failure. Of the remaining 23 observers, 13 were men and 10 were women. The 23 observers ranged in age from 21 to 75, with the mean age of 37. Observers possessed a driver's license and a minimum visual acuity of 20/40. Observers were recruited from the population where the field evaluation was conducted (Ft. Eustis, VA), and paid a minimum of $50 for their services, plus whatever they "won" from their participation in the experiment.

Observers were organized in groups of four. Before the start of the study, the experimenter welcomed the observers and described the purpose of the experiment. Each observer's foveal visual acuity was measured as well as their peripheral vision. The experimenter told the observers that the purpose of the experiment was to learn how train detection varies as a function of differences in locomotive appearance. Observers saw each of the alerting light system arrangements before the start of the trial. Observers participated in four practice trials to become familiar with the three tasks, which were followed by the experimental trials. Observers had five minute rest periods approximately every half hour of testing. Following completion of the experiment, observers were debriefed regarding the four alerting light systems and completed a brief questionnaire requesting their opinions about the relative effectiveness of the four experimental alerting light systems.

The primary visual display consisted of a white two-headed arrow displayed on the laptop computer monitor. The two-headed arrow was displayed against a black background. The height of the display was 152 mm (6 in) and had a viewing angle of 20^{o}.

Half the observers were assigned to the daylight condition and half were assigned to the darkness condition.

D-2 EXPERIMENTAL TRIAL PROCEDURES

Each alerting light system activation was repeated twelve times for a total of 48 trials. For half the trials, the locomotive moved in one direction (i.e., from left to right, relative to the observer position). For the other half, the locomotive moved in the opposite direction (i.e., from right to left, relative to the observer position). The presentation order of the four alerting light system conditions was randomized.

When the trial began, the locomotive approach was delayed by one of three random intervals: 15, 30, and 45 seconds, to minimize guessing by the observers. Since there were twelve replications for each alerting light system condition, each condition received four repetitions at each of the three delay intervals. Within each alerting light system condition, there were three replications of each arrival time estimation interval.

D-3 OBSERVER INCENTIVE SYSTEM

An incentive system was established to maintain observer attention on the visual monitoring task. Each of the observers received a monetary reward for every correct identification of the down arrow. To receive a reward, observers had to respond correctly within 1 second of the event (onset of the down arrow). Observers earned 8 points for each correct response, where 1 point represented $0.01. Observers lost 16 points for every observation error or miss.

Observers received a monetary reward for detecting the locomotive. The reward amount depended upon the distance of the locomotive from the crossing; the amount decreased as observers detected the locomotive closer to the crossing. For detecting the locomotive 610 m (2,000 ft) from the crossing, the maximum distance, observers earned 10 points, where 1 point represented $0.01. The reward declined 1 point for every 45.8 m (150 ft) closer to the crossing, the observer detected the locomotive. Observers lost 100 points for each selection error. A selection error occurred if observers pressed the wrong arrow key, representing the wrong locomotive approach direction.

Observers also received a monetary reward for estimating the locomotive's time to arrival. The reward amount depended upon the accuracy of the observer's estimate; the amount decreased as the arrival error (represented by the difference between the actual time to arrival and estimated time to arrival) increased. For an arrival error of zero seconds, the observer earned 50 points, where 1 point represented $0.01. The reward declined 2.5 points for every 1 second increase in arrival error, until the arrival error reached 20 seconds when the number of points earned was zero. For an arrival error above 20 seconds, no points were earned or lost.

An observer could earn an average of $43.20 if no errors were made on the visual monitoring task and $4.80 if no errors were made on the peripheral detection task. The larger amount that could be earned on the visual monitoring task compared to the peripheral detection task was designed to keep observer attention and direction of gaze directed forward as it would be under normal driving conditions. The large penalty for selecting the wrong locomotive approach direction was designed to discourage guessing. The observer could earn \$24 if no errors were made on the time estimation task. However, it is unrealistic to expect no errors on this task. For an average error of 10 seconds, the observer would receive \$12.

At the end of each trial, each observer received feedback regarding their performance. The computer showed four numbers representing the amount of money earned. Three numbers showed the amount of money earned on the completed trial for the visual monitoring task, peripheral detection task and time estimation task, respectively.
The fourth number showed the cumulative total earned for all tasks over the number of trials completed.

Observers also received \$50 for their participation in the experiment, in addition to what they earned in the experiment.

D-4 LOCOMOTIVES AND ALERTING LIGHTS

Two General Motors (EMD) GP-9 locomotives were each equipped with the standard headlight, as well as the ditch, crossing and strobe light systems. The standard headlight consisted of two General Electric PAR 56 locomotive headlights mounted vertically 255 cm (102 in) above the top of the rail. The headlight was a 350-watt sealed-beam incandescent bulb with a horizontal beam width of 3.5^o and a vertical beam width of 3.5^o. The standard headlight was aimed down the track centerline, parallel with the longitudinal axis of the locomotive.

The ditch light system used the same GE 350-watt PAR 56 locomotive headlight found in the standard headlight. The ditch lights were positioned 163 cm (64 in) above the top of the rail, on each side of the front and rear. The ditch lights were aimed 15^o outward from the track centerline.

The crossing light system used the same GE 350-watt PAR 56 locomotive headlight found in the standard headlight. The crossing lights were also positioned 163 cm (64 in) above the top of the rail, on each side. Each crossing light was aimed horizontally parallel with the track centerline and flashed at a rate of 58 flashes per minute.

For the strobe light system, two Quest Apollolite xenon strobe lights were used. The bulb was a xenon flash tube enclosed within a frenal lens, with an effective light intensity of 1,000 candela and a horizontal beam width of 180^o. The two strobe lights flashed continuously, alternating at a flash rate of 80 per minute for a total of 160 flashes per minute.

D-5 OTHER TEST EQUIPMENT

Each observer wore a pair of Pelltor headphones to block the sound of the approaching vehicle. The headphones attenuated the sound of the locomotive by 25 dB. Pink noise with a sound level of 50 dB was pumped through the headphones to further mask the sound of the locomotive. These measures were intended to prevent the observer from using auditory cues to detect the presence of the locomotive.

Each observer used an IBM compatible 386/25 mhz laptop computer to record their response to the central visual task and the peripheral visual task. The computer recorded the distance at which the observer detected the locomotive and estimated the time of its arrival.

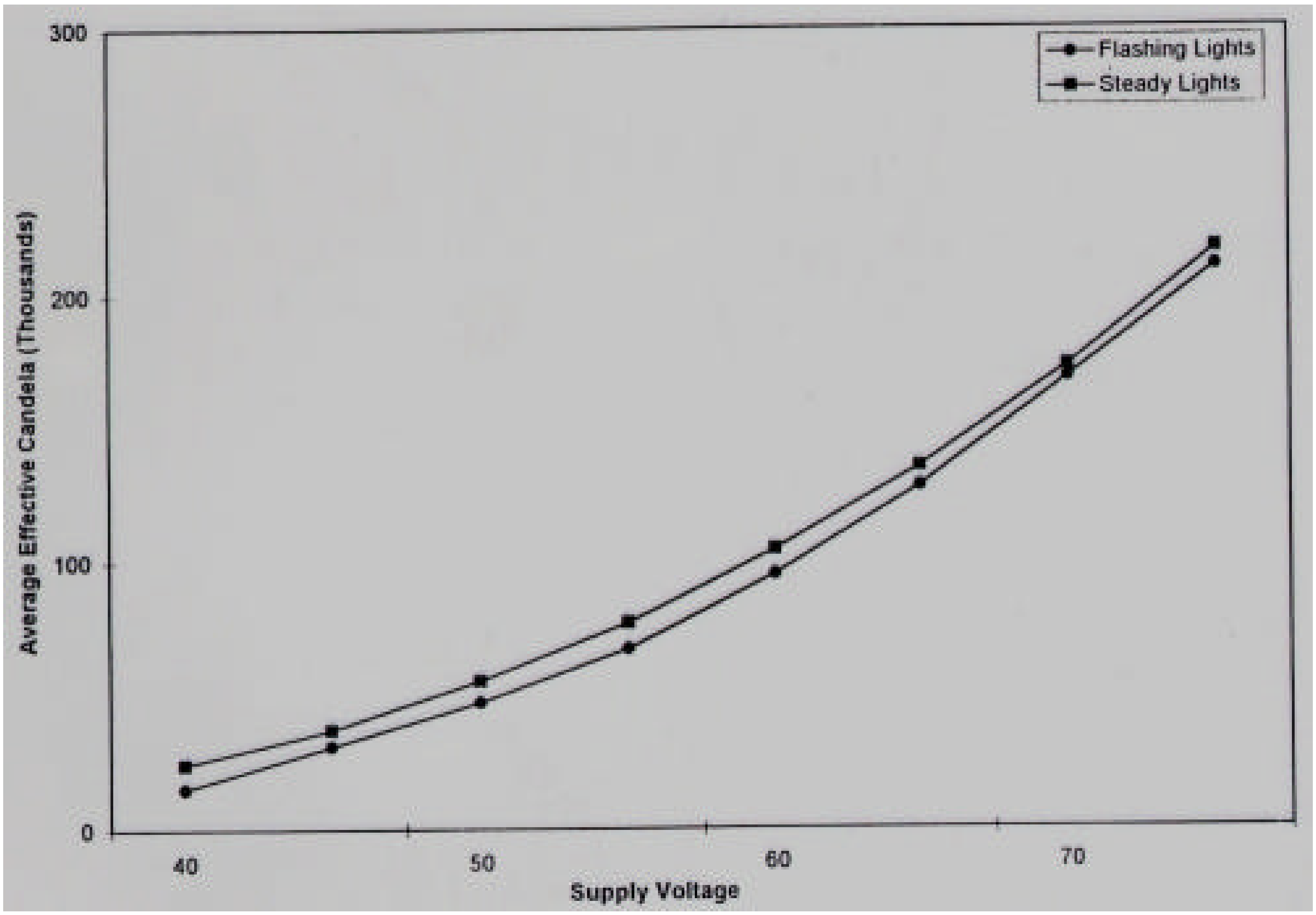
At periodic intervals, an experimenter used a Soligar Spot Sensor II light meter to measure horizontal and vertical ambient light levels (illuminance) in lux (lx), as well a Davis light meter to measure sky ambient light level (luminance) in footlamberts (fL), to account for changes in ambient light levels that might influence observer detection performance. No relationship was observed between ambient light level and the perceived brightness of any of the alerting lights.

To measure the distance of the locomotive from the simulated grade crossing, the number of wheel revolutions were recorded. The signal measuring the number of wheel revolutions was translated from an electrical signal into a tone pulse by a custom-built pulse encoder. The tone was relayed by a Motorola R-NET radio via a rooftop antenna to the laptop computer at the experimenter's station. The number of wheel revolutions was used to calculate the distance traveled over the tracks and subtracted from the 610 m (2,000 ft) locomotive starting point.

Experimenters in the locomotives communicated with experimenters at the observer station using Motorola MT1000 two-way radios.

APPENDIX E. PEAK LIGHT INTENSITY AS A FUNCTION OF POWER SUPPLY VOLTAGE

This graph plots the effect of voltage on peak light intensity for two 350 watt, 75 volt PAR 56 headlamps. Peak intensity is plotted
for steady and flashing conditions.



Source: Quest Corporation

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