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TORISTS' REQUIREMENTS FOR ACTIVE ADE CROSSING WARNING DEVICES

OCTOBER 1977
Final Report

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FOREWORD

This report describes a two-year study aimed at improving grade crossing safety through a better understanding of motorists' needs at crossings with active devices. Emphasis was placed on improving the conspicuity of active devices through add-on modifications such as strobe lights. Laboratory tests were conducted at the FAA Low Visibility Research Facility in Richmond, California to determine the effects of color, flashrate, brightness, size, and placement under daylight, darkness and daytime fog conditions. Based on the laboratory tests two modifications to active grade crossing warning devices were field tested at actual grade crossings in California. The first modification consisted of three eight-inch white strobe lights added to a standard flashing light unit at a high accident rate urban crossing. The second was a gate arm modification consisting of three small red, white, and blue strobes installed at a rural crossing with high speed truck and automobile traffic. Only limited field testing was undertaken during the study and the potential safety benefits of such add-on devices was not determined during the course of the study. The FHWA Office of Research plans additional work in this area to determine the potential safety benefits and installation and maintenance costs of such add-on devices.

Sufficient copies of this report are being distributed to provide one copy to each FHWA regional office, one copy to each FHWA division office, and one copy to each State highway agency. The division and State copies are being sent directly to the division office.

Charles F. Scheffey
Charles F. Scheffey
Director, Office of Research

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16. Abstract

This report describes a two-year study of some of the basic problems involved in improving the design of active warning devices intended to make motorists more aware of grade crossing hazards. Emphasis was placed upon improvement of the attention-getting aspect (conspicuity) of active crossing warning devices which was presumed to positively correlate with improvements in grade crossing safety. An indoor laboratory test was conducted in the FAA Low Visibility Research Facility located at the University of California. In excess of 150 subjects gave over 20,000 responses to flashing light displays. Results were analyzed to determine effects of color, flash rate, brightness, size and placement under daylight, darkness and daytime fog conditions. The laboratory tests resulted in development of two improved devices which were field tested on actual grade crossings. The first device consisted of an array of three eight-inch white (clear) strobe lights added to a standard flashing warning system at a high accident rate urban crossing in Richmond, CA. The second was a gate arm add-on device consisting of three small strobes, red, white (clear) and blue in color installed at a rural highway grade crossing with high speed truck and automobile traffic. Due to project constraints, no long term safety improvement analysis could be conducted. Because there was no evidence of driver confusion during the conduct of these field tests, it was concluded that colored lights other than red can be used in moderation as add-on to existing active crossing warning devices to increase the attention getting property of the warning system. The high composite (not from a single source) flash rate devices that were installed did not result in any erratic driving behavior on the part of approaching motorists.

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Railroad Crossing Warning Systems, Flashing Lights, Strobe Lights, Conspicuity

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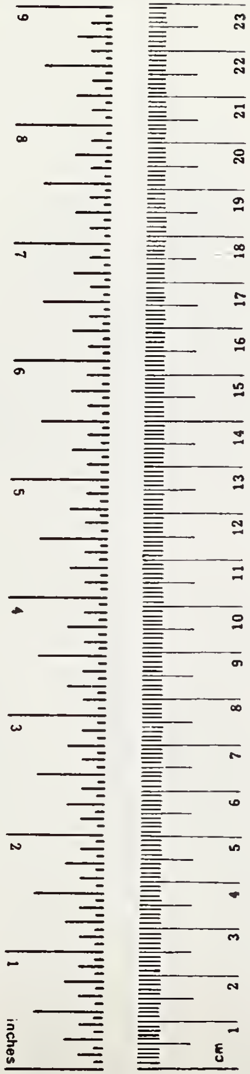
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

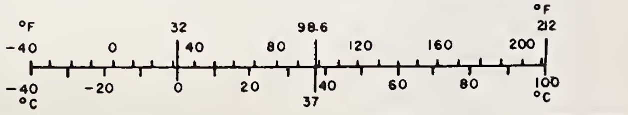
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

This report describes research work conducted under contract DOT-FH-11-8846. The objectives of this study were first to establish the relative "conspicuity"* of various configuration of alternately flashing lights and other active warning devices under daytime conditions, nighttime conditions, varying weather conditions, and varying background conditions, and second, to field test and evaluate new or improved devices, based on laboratory test results, that may show practical promise for improvement in gaining the attention of motorists as they approach grade crossings.

Each year, over the past ten years, there have been approximately 12,000 train involved grade crossing accidents in the United States resulting in approximately 1,200 deaths and 7,000 injuries. Railroad grade crossings with train-activated warning devices constitute approximately 20 percent of the nations public crossings. However, this 20 percent or approximately 49,000 crossings account for 40 percent of all train involved crossing accidents. If all conditions were equal one would quickly conclude that the hazard (or hazard rate) at an actively protected public grade crossing was 2.67 times that of a non-actively protected public grade crossing, however, this disproportionate share of accidents may be due to higher rail and highway traffic volume conflicts occurring at the active device locations.

What remained was; that full explanation of these disparities was impossible and therefore it was concluded that the fundamental elements of active crossing warning systems should be scrutinized as to their ability to provide adequate and reliable information to the motorist of imminent hazards.

Based on results of previous studies of motorists' behavior, it appeared that there are two basic considerations which are involved in the effectiveness of train-activated warning devices: credibility and conspicuity. It was the goal of the project to explore only the conspicuity question. It is presumed that increasing the

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*See Glossary

conspicuity of grade crossing warning devices will reduce crossing accidents.

1.1 Overview

1.1.1 Add-On Devices

Conduct of the study, aimed at increasing the attention getting property of active crossing warning systems, focused upon the add-on approach rather than the in-lieu-of (substitution of new devices for existing devices) approach for the following reasons:

1) From a color standpoint, the in-lieu-of approach would certainly confine the research to the color red or at the most red and amber, based upon the meaning drivers attach to these colors, and as prescribed by the MUTCD.

2) The research team did not want to alter the basic integrity of the active railroad crossing warning devices because many state traffic laws and regulations are worded around a portion of the activated device itself, e.g., the continuous on-time of the red incandescent light located at the gate tip of a gate protected crossing; the low prohibiting vehicular movement around, under, over, etc., a lowered gate arm marked with a steady burn red light at the gate tip.

Another rule applied to the conduct of the project, was to restrain the development of add-on devices to the extent that any field installation of the improved, add-on device(s) would not destroy the basic integrity of the existing activated warning system by so focusing driver attention to the add-on device that he will fail to see and comprehend the meaning of the rest of the system with which he is familiar.

1.1.2 Color Considerations

Generally speaking, but not without exception, white lights are used for illumination, while the colored, (non-white) lights are used to attract attention both on and off the roadway. If there is competition from other colored lights (flashing or steady burn) one usually increases the size or brightness of one's own colored array. Therefore, where safety is at stake it may well make sense to use a non-filtered white light source in a flashing mode to attract the driver's attention.

The competing, attention getting properties of colored lights are easily overcome (at lower power consumption) by the intensity of the flashing white warning lights, while the competitive white, steady burn, higher intensity, illumination lights are overcome by flashing the safety related, lower intensity white light source. What one must be extremely careful about in application of this approach is not to overcome other safety related, non-white, flashing or steady burn lights reflectors, etc., necessary to attract driver's attention to other warnings in the local environs.

In this regard, an interesting unanswered question is, "Have we so over done the use of red and amber lights and reflectors and the amount of warning and delineation for the driver in an urban area, that he finds difficulty in "tuning in" another set of flashing lights be they red or amber, particularly at night?" The foregoing rhetorical question was stimulated by a comment of a test subject during debriefing following her exposure to the white strobe light configurations in an outdoor laboratory test of driver response. Having had the safety aspects of the project explained to her, the woman volunteered something on the order of "If you are trying to get peoples' attention, I'm happy to see you are not using red or yellow."

1.1.3 Visual Process

One of the most gratifying results of the conduct of the project was the development of a better understanding of the visual process as related to brightness sensation and color recognition, a very poorly documented subject and, hence, not well understood process. Appendix B discusses this subject in more detail, however, a brief summary is included here so the study results and conclusions will be more fully appreciated in the sections to follow.

Simply speaking there are four fundamental components of color recognition and brightness sensation each of which can be described by some examples which are all readily observable to the non-color blind individual, i.e.,

1) Observed relative brightness; e.g., between a red lens and a blue lens when first illuminated by an incandescent bulb and then illuminated secondly by a neon tube of the same wattage.

2) Perceived color difference; e.g., red and blue, in example one above.

3) Observed color change; e.g., approaching car headlights, at night, through fog, as they are first seen (yellowish) and gradually turn to white as the car passes at close range.

4) Apparent color; e.g., of the "green" face of a traffic signal in bright daylight (green), versus its color at night with few competing background lights (blue-green).

The foregoing examples illustrate, respectively, the four fundamental components of color recognition and brightness sensation mentioned previously, i.e.,

1) The spectral energy output distribution (spectrum) of the light source; the incandescent bulb is "richer" (more energy) in the red region while the neon tube is richer in the blue region of the visual wavelength spectrum.

2) The wavelength transmittance of the lens (roundel or filter) through which the source energy is transmitted; the red lens transmits the red wavelengths and attenuates or filters other wavelengths, with the blue lens similarly defined.

3) The wavelength transmittance or attenuation characteristics of the medium, between the source filter and the eye. Fog attenuates (refracts) shorter wavelengths (blues) more severely than longer wavelengths (reds), resulting in a changing wavelength spectrum, reaching the eye, as the vehicle closes the distance to the observers' eye.

4) The wavelength (color) sensitivity of the eye itself; partial nighttime eye adaptation increases the sensitivity to the blue wavelengths, which are abundantly transmitted by the green (blue/green) lens of the traffic signal.

The impact of the foregoing was clearly evident in conduct of the laboratory test phase (see Section 4) of the project where it became extremely difficult to achieve even moderate brightness levels of blue lights when the light source was an incandescent bulb. Similarly, on the other extreme, the use of a xenon flash tube, rich in the blues and poor in the reds, behind a red lens (filter) ran a very poor "second" to the standard, narrow beam, railroad flashing light pair, despite higher energy consumption of the strobe light.

1.1.4 Traffic Signal Counterpart

An active warning device at a grade crossing is either on or off; it has no pre-warning* of turn-on such as do street traffic and rail traffic signals. These devices have evolved by trial and error so that the vehicle operator is given some warning that his right of way is going to be removed. Traffic signals also are lighted continuously (or flashed) and therefore present a bright target that is available as far away as it can be seen.

Grade crossing warning lights, on the other hand, are dormant and present a relatively inconspicuous target until they are activated. The crossbucks are large it is true but not bright and they are the same configuration at passive crossings. Therefore, the standard flashers depend solely on their own conspicuity to capture the attention of the on-coming motorist. This study shows that a color difference (white), a flash rate increase (strobe), and the use of multiple (three) signal faces is correlated with increased conspicuity in a competing signal environment.

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*Wilde, G.J.S, Cake, L.J., and McCarthy, M.G., "An Observational Study of Driver Behaviour at Signalized Railroad Grade Crossings," Canadian Institute of Guided Ground Transport, Queen's University, Kingston, Ontario, 1975.

1.1.5 Novelty Effects

Most all developmental studies of traffic control devices are plagued by the possibility that the test driver subjects are merely reacting (better, sooner or quicker) because the experimental device is unusual or novel to them. Current use of red strobes in grade crossing red flashers could owe some of their apparent increase in effectiveness to the fact that to date only a few crossings have had red strobes installed.

In the present study, the driver subjects were exposed to several hundred presentations of strobes and other signal configurations. Therefore, to some extent, the novelty effect of the strobes was reduced. This could account for some of the results. For example, the red strobes did not succeed in capturing the subjects' attention any better than the standard red flashers; and if red strobes were installed universally, they might not bring about any real improvement unless due to their wider beam width, they are more conspicuous. This study could not test for this possibility.

1.2 Summary

The conduct of the two-year study naturally separated itself into three phases which are briefly discussed as follows:

1.2.1 Phase I - Literature Survey

This phase is reported in Section 3, while the annotated bibliography, developed during this phase, appears in Appendix A to this document. Upon completion of the literature survey, a plan for laboratory testing was developed for conduct of Phase II. This plan included what variables would be tested. The primary variables for initial testing were color, flashrate, brightness, size and placement.. Laboratory tests were conducted in the Federal Aviation Administration's (FAA) Low Visibility Facility (Fog Chamber) located in the University of California's Richmond Field Station.

1.2.2 Phase II - Laboratory Tests

The summary results of this phase are discussed in Section 4 while the statistical procedures of data analysis and detailed presentation of the laboratory test data are contained in Appendices C and D respectively. The primary variables of color, flash rate, brightness, size and placement were tested using the incandescent bulb as the primary source of light energy. However, some low power strobe (xenon flash tubes) lights were periodically used to provide highly competitive decoy targets for test subject selection in brief test subject exposures (1.5-4.5 seconds) to a set of targets (displays). Results of this test of pairs of lights essentially verified past literature conclusions which were done with single lights.

The test subjects were not distracted by some ongoing task. The test situation was structured to represent a typical driving situation where the motorist suddently directs his attention to the crossing signal(s) and may or may not become attracted by any particular one.

Summary laboratory results were:

1) Red and blue are good daytime and nighttime colors, respectively.

2) Size increase, 8 inches to 12 inches,* shows more promise for increasing conspicuity than increased luminance, where background competition is present.

3) Right side of the roadway and overhead (cantilevered) light placement appears to be the most conspicuous (Appendix D, section 6).

4) Flash rates exceeding 70-90 cycles per minute for incandescent light sources will result in decreased attention-getting properties; likely due to filament heating and cooling characteristics of the light source (Appendix D, section 3).

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* 8 inches = 20.3 cm
12 inches = 30.5 cm

When the laboratory tests proceeded into their second stage and testing of xenon flashtubes began, a number of very conclusive results were achieved. A summary of these are as follows:

1) Subject to limitation of 17 Joules, of stored energy per lamp discharge of the xenon flashtube, a sealed beam flashing pair of these red lens covered strobes did not approach the attention getting property of a pair of narrow beam 8-inch* red railroad flashing lights with reflectorized 18-watt bulbs measuring roughly 32,000 fL* at beam center (Appendix D, section 7).

2) A 17 Joule xenon flashtube pair with one red and one blue filter did compete favorably with the aforementioned 8-inch* railroad flashing lights (Appendix D, section 7).

3) Seventeen (17) Joule, and lesser powered, xenon flash tubes without colored filters (lenses) either completely or partially dominate the attention getting property of 8-inch* railroad flashing pairs, in one, two or three, white light combinations (Appendix D, sections 7 and 8).

4) There is a definite increase in the attention getting property of strobe lights as the flash rate is increased and in particular, the three strobe light configuration (see Figure 12) when certain flash patterns produce the sensation of light movement (phi phenomenon).

5) Gate mounted red, white and blue, low powered strobes significantly add to gate arm conspicuity under medium and high contrast conditions. (Appendix D, section 9 and Figure 17).

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* 8 inches = 20.3 cm
32,000 fL = 109640.288 candelas/meter^2

6) Multiple white strobe lights were tested at combined flashrates ranging from 120-480 flashes per minute. The multiple white strobes were most conspicuous at irregular flash patterns and at flashrates totalling 360-480 per minute. No indication of erratic driving was observed with the multiple units that were field tested (Appendix D section 8.)

The laboratory tests were concluded with recommendation that the three 8-inch* white strobe unit configuration, mounted 30* inches above an existing pair of railroad flashers, be field tested at a flasher protected crossing. Three low power gate-mounted strobes (red, white and blue) were recommended for add-on device field tests at a gate protected crossing.

Prior to actual field installation of these add-on devices, both were briefly tested in an outdoor laboratory driver response test. They were presented to unsuspecting drivers in a non-competitive roadway environment under both daytime and nighttime conditions. Even though operated at considerably higher power than would be employed in field installations, these devices produced no adverse driver behavior in the outdoor, pre-field installation tests.

1.2.3 Phase III - Field Tests

There were two field test site locations where improved driver attention getting devices were added to existing crossing warning systems. The discussion of these installations and test results are contained in Section 5; summary results are listed below.

1.2.3.1 Field Test of Eight-Inch Triple White Strobes

A triple white add-on strobe light configuration was tested at a flasher protected Santa Fe Crossing located in Richmond, California (see Figure 16). This crossing has been characterized

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* 8 inches = 20.3 cm
30 inches = 76.2 cm

by an average of 2.3 vehicle/train accidents per year over the 12 year period (1964-1976). There was one (1) fatality accident (2 deaths) and eleven (11) injury accidents over this time span.

Train activity, crossing activations, can go as high as 100 per day of which only 50-75 involve a train crossing the roadway. The roadway is a six-lane traffic signalized arterial having an average daily traffic volume of approximately 25,000 vehicles per day. Location of the crossing is at the southern end of the Santa Fe switching yards where a number of daily activations consist of a switch engine creeping up to the crossing, stopping short of the vehicle roadway conflict zone and then receding from the crossing on another Santa Fe track. Despite an observable erratic driver behavior in daytime which has been termed a game of "chicken" with the train, approximately 90 percent of the accidents occurred during darkness.

The cantilevered set of three white strobe lights were mounted horizontally 30 inches* over a pair of railroad flashing 12-inch* heads cantelevered over the center lane of the three approach lanes in each direction (Figure 16). The strobe controllers were tied directly into the Santa Fe activation circuitry and flashed with the crossing signals. The strobes would continue to flash with the railroad flashers until:

1) The train occupied the crossing conflict zone

or

2) The crossing activation was terminated without the train occupying the crossing conflict zone

or

3) A maximun, selectable, time interval was exceeded.

The multiple white strobes flashed compositely at 480 flashes per minute. The outside pair alternated at 120 cycles per minute and

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* 30 inches = 76.2 cm
12 inches = 30.5 cm

the center strobe trailed each outside strobe flash by .050 seconds. The strobe energy per discharge flash was 5.6 Joules daytime and 2.8 Joules nighttime with darkness switching of power done by a photocell. The nighttime energy setting was at least a factor of three below what could have been used for the nighttime settings without blinding the driver. How much power could be applied to the white strobes in daytime, bright sunlight, before they would present a blinding hazard to the staring vehicle driver, was not evaluated in the research project.

The strobes were activated on 1 April 1977, following a frustrating debugging problem, and continued to operate flawlessly through 19 July 1977. They were removed by Santa Fe personnel on 20 July 1977 in favor of a single red (standard color) lens covered strobe which could be maintained by Santa Fe personnel.

Over the 1 April - 19 July time period there were no reported vehicle train accidents. There was no evidence of any driver confusion or erratic behavior during the data taking effort, following activiation of the strobe lights. No driver was ever observed staring at the lights during his approach to the crossing.

1.2.3.2 Field Test of Gate Mounted Strobes

Three strobe lights (red, white and blue) were added to the gate arm of a gate protected crossing located in a remote rural highway location in the southern California desert. The strobes being far more visible than the gate mounted incandescent lights did produce significant earlier (upstream) approach vehicle decelerations in the daytime. There was no appreciable difference at nighttime, since in the lack of competitive background lights the existing incandescents were literally visible for miles.

This field test site was not the most desirable location for testing gate mounted strobes since their applicability or addition to existing gate mounted incandescent lights would rationally prescribe an urban located crossing where nighttime background light competition was intense. Test site observations paralleled those of the laboratory (Appendix B, section 9) relative to "ineffectiveness" of the red filtered strobe as compared to the blue filtered strobe or non-filtered (clear-white) strobe.

2.0 CONCLUSIONS AND RECOMMENDATIONS

Based upon results of the laboratory and field test phases of the project, a number of conclusions and research recommendations can be drawn.

2.1 Conclusions

1) A pair of 17 Joule red filtered xenon strobe lights alternately flashing at 60-120 cycles/minute were less conspicuous than 8-inch* narrow beam railroad flashing lights measuring 32,000fL* at beam center, when test subject observations were made at 420-450 feet* and both targets viewed at an angle close to beam center. Tests were not conducted off beam center. Strobe lights produce a wider beam and therefore may be more effective in actual field installations. Project constraints did not permit test of this possibility.

2) There are definite increased conspicuity advantages to be realized in increasing the flashrates (two per second or higher) of add-on strobe powered crossing warning lights. This increase in flash rate will consume additional electrical power.

3) White xenon strobe lights, supplementing standard red railroad flashers, add significantly to the conspicuity of the array. Two strobes are better than one and three are better than two.

4) With equal flashrates, size and luminance, there is no basis to expect significant improvements in conspicuity of incandescent powered railroad flashers by changing to some color other than red, i.e., orange, amber, etc., although white (clear lens) incandescent flashers were not tested.

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* 8 inches = 20.3 cm
420 feet = 128.1 meters
450 feet = 137.3 meters
32,000 fL = 109640.288 candelas/meter^2

5) Flashrates ranging from 55 to 90/minute are the most conspicuous rates for alternately flashing pairs of red <u>incandescent</u> lights with 50 percent duty cycle.

6) Right side of road and cantilevered mounting of flashing pairs of lights are preferable to high-mounted, right side of roadway location.

7) Both retro-reflectors and stop signs add to the attention getting property of the gate arm. Due to weight problems and a non-measured impact of partially visible stop signs in a raised gate arm position (non-activated crossing), retro-reflector installation on the existing gate arm is considered a more feasible addition to a red and white gate arm than a pair of hanging stop signs.

8) There appears no uniform solution to increasing the conspicuity of active grade crossing warning systems, although the add-on white strobes as tested in the laboratory and field show most promise for improving the attention getting properties of railroad crossing warning systems. What such an installation will do to accident rate reduction is an unaswered question, in addition to the fundamental question of what portion of activated grade crossing train/vehicle accidents are really realted to lack of crossing signal conspicuity.

2.2 Research Recommendations

1) A number of two unit and three unit, eight-inch* low powered white strobe light installations should be trial tested at high accident rate crossings. These installations should be operated on a long-term basis, so that the vehicle influence on train accident rates can be ascertained.

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* 8 inches = 20.3 cm

2) Trial tests should also be conducted of a 12-inch* light red, 70-degree horizontal spread lens, powered by an 18-watt reflectorized bulb (see Appendix D, section 7.0) or conventional 25-watt bulb.

   There is approximately a 4 to 1 gain in luminance in using a lighter red roundel coupled with the 18-watt reflectorized bulb over the darker red roundel and nonreflectorized bulb. The 12-inch* 70-degree spread lens may well be less intense at beam center than the narrow beam roundel. However, at 32,000 fL* the narrow beam roundel may be already excessively bright--increased size of the head (Appendix D, section 6.0) contributes far more to conspicuity than does increased luminance (at these brightness levels).

3) Trial tests of gate mounted strobes should also be continued. Two small strobes should be mounted between the existing three incandescent powered lights on the gate arm. It is suggested the strobes be clear (white), although two-pole blue filtered strobes would be an acceptable (less conspicuous) alternative. High flash rates (at least 110/minute per light) and irregular flash patterns are suggested. It is recommended that such installations incorporate the use of vehicle sensors to turn the strobes off when a vehicle has stopped in front of the lowered gate arm (see section 6.0). The most warranted locations for such tests is the urban located crossing where there is a lot of nighttime background competition.

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* 12 inches = 30.5 cm
32,000 fL = 109640.288 candelas/meter^2

3.0 PHASE I - LITERATURE SYNTHESIS

The first phase of the project was a literature synthesis aimed towards development of an experimental plan for conduct of the laboratory tests in Phase II of the project. An initial list of factors for consideration in laboratory tests included color, shape, beam width, size, brightness, brightness contrast, flash rate, flash duration and duty cycle. Based upon results of the survey a number of these factors, those showing most promise for grade crossing warning device improvement, would be those treated in the experimentation.

3.1 Literature Survey

A summary of the contents of the bibliography (Appendix A) is presented in succeeding sections. References to the bibliography are made by author's last name and year of publication.

The first comprehensive review of the human factors principles associated with the grade crossing problem appears as an appendix to an NCHRP report by Schoppert and Hoyt (1968). This review considers the needs that must be met by both active and passive devices in alerting the driver to both the presence of a crossing and the presence of a train. These, of course, are two quite separate problems, and require somewhat different approaches.

The project was concerned with providing indications of train presence through the use of warning devices that are activated only when the train is in the vicinity of the crossing. Of the recommendations made in the Schoppert and Hoyt report, only a few were of direct relevance to this project. These included:

1) The use of intermittent stimulation (e.g., flashing lights).

2) The removal or minimization of stimuli such as signs or signals in the vicinity of the crossing that are irrelevant, distracting or even competitive with the grade crossing warning devices.

3) The provision of redundant warning, either by repetition of the warning or by cross-modality stimulation (e.g., using horns in addition to lights).

3.1.1 Sound Stimulation

A study by Aurelius and Korobow (1971), addressed both the visibility and audibility of approaching trains. They recommended panels of bright colored paint and xenon strobe lamps on the locomotive to make it more visible. They report that in high-speed encounters, the sound level of locomotive horns necessary to provide reliable warning to motorists would be too high to be environmentally acceptable. This finding is supported by work by Henderson and Burg (1974), who state that due to the high noise level inside passenger cars moving at speeds from 35 to 60* mph, sounds generated by automobile horns, emergency vehicle sirens and even train whistles have little warning value, except under certain favorable circumstances. Drivers of higher noise level vehicles, such as trucks and motorcycles, experience even greater difficulty in hearing signals of interest.

Henderson and Burg suggest modifications to vehicles to provide lower interior noise levels plus in-vehicle sensors to pick up sound signals external to the car. Longrigg (1975), suggests the use of static, directional sound sources positioned at the crossing. This is an interesting concept, and one that merits its own carefully-controlled study.

3.1.2 Visual Stimulation

Active crossing warning devices that have found usage thus far include flashing lights, steady lights, moving lights (wig-wags), gate arms and bells. Lights constitute by far the most prevalent form of active warning at crossings--by themselves or in combination with gate arms and bells. The major characteristics of lights that must be considered as having an impact on their effectiveness as warning devices include steady versus flashing, color, intensity (and contrast), flash rate, size and placement as well as numbers of lights.

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* 35 mph = 56 km/hr
60 mph = 96 km/hr

3.1.2.1 Flashing Versus Steady

There is more than ample evidence to demonstrate the superior conspicuity of flashing lights over steady lights. As Cole (1972) points out, flashing lights are more conspicuous because they occur rarely in nature, and the visual system is not well prepared for flash stimulation. Gerathewohl (1954) demonstrated the superiority of flashing light signals in the laboratory under conditions of low brightness contrast, and a number of "before-after" type studies have clearly shown an improvement in accident experience or safe driving behavior after the installation of flashing beacons or lights at problem locations (e.g., Butcher (1973); Mitchell (1972); Foody and Taylor (1972); Cribbins and Walton (1970); Cribbins, Bennett and Walton (1969); and Schoppert and Hoyt (1968). These studies also illustrate a general finding that drivers approach a crossing at slower speeds (i.e., more cautiously) as the warning stimulus grows progressively greater.

3.1.2.2 Color

A number of papers bear upon the role of color as an element of warning. Nathan (1969) found that blue or yellow make distant objects appear closer (a good safety margin), while other research has shown that red makes objects look further away. Cole (1972) points out that color contrast can act as a partial substitute for luminance contrast by providing an additional cue for discrimination (although at a distance, luminance contrast is far more important).

Perhaps the most significant study conducted to date relevant to the problem at hand was by Rumar (1972), who investigated the effects of color on the conspicuity of flashing or rotating beacons for emergency vehicles. Rumar found that from a peripheral conspicuity point of view (the signal was offset from 10° to 98° from the line of sight), the red beacon is inferior at night but good in bright daylight. Blue is poorly visible in the daytime but very good at night. Orange was found to be good both in the daytime and at night.

Hopkins and Holmstrom (1975) point out that lighter shades of red provide a higher degree of light transmission than do the darker shades of red which have customarily been used (and which reduce transmission by as much as 90 percent).

3.1.2.3 Intensity

In choosing an intensity for use with signal lights one has to consider a number of other factors, such as ambient illumination, background, size, and so on. In general, a light that is sufficiently bright to provide relatively errorless detection during the daytime may be so bright as to be uncomfortable at night. Brown and Cole (1969) assert that 200 candelas is the minimum intensity necessary for daytime use, and is sufficient for detection by an alerted driver against the commonly-found urban background conditions. Lindberg (1971) states that the minimum brightness necessary for a flashing red signal to be detected in daylight probably lies between 100 and 400 candelas for a lamp the size of a crossing signal. Hopkins and Holmstrom (1975) suggest that 200 to 500 candelas may be an acceptable range of intensities for night viewing. Loss of light transmission due to intervening media such as windshields, spectacles, fog, dust, etc. has to be taken into account in deriving an appropriate intensity. Projector, et al. (1962) found that signal detection was highly sensitive to back scatter from one's own headlights as a function of atmospheric transmissivity.

It is the general consensus of many researchers that current practice in providing crossing signal light source calls for low power consumption due to the need for standby battery operation capability. To meet this constraint, narrow beam widths are used to maximize intensity and minimize power consumption. Unfortunately, this makes aiming highly critical, and as Hopkins and Holmstrom point out, sometimes results in a warning system that is only marginally adequate.

Hartsell (1969) reported that the trend was towards narrower beam widths and more precise aiming, not only to direct maximum intensity down the road to the driver, but also to minimize discomfort for viewers not on the highway and reduce confusion with emergency vehicle beacons. Hopkins and Holmstrom (1975) point out that narrow-beam lights provide good detectability at a distance, but once the driver moves out of the beam, the intensity falls off sharply; by contrast, the wider beams sacrifice peak intensity but the driver stays within them over a much greater distance. The AAR Signal Manual, Part 268, "Signal Instructions: Aligning Highway Crossing Signal Reflector Type Light Units (1972)" illustrates methods of aligning light units. These illustrations indicate the practice of using far side, back light flashers to provide the necessary "close up" signal intensity, particularly where long range, narrow beam width roundels are used in the "near-side" flashers.

3.1.2.4 Contrast and Background

Related closely to intensity, of course, are contrast and background. Background luminance (luminance contrast) and color (color contrast) are critical for signal detection (NAS-NRC Committee on Vision, 1975). A study by Century Research Corporation found that competition from stimuli (e.g., city lights) in the background can greatly degrade signal detection performance (Anonymous, 1962). The highest degree of signal detection degradation was reported to be against city light backgrounds of high intensity and/or those containing concentrations of many lights, and/or one or more flashing lights, and/or a variety of colors. In general, irrelevant background lights degrade visual detection (Brown and Cole, 1969).

Gerathewohl (1952, 1957) reported that reaction time to flashing signals decreases with increasing contrast (within limits). Gerathewohl used contrasts of 0.19 (low), 1.00 (medium) and 74.2 (high) in his study.

3.1.2.5 Flash Rate

Current recommended combined flash rates for crossing warning signals are 35 to 55 flashes per minute (AAR Bulletin #7, 1974), but the basis for this standard is not given. In general, reaction time to flashing signals decreases with increasing frequency within limits (Gerathewohl, 1953), and it has been suggested that a progressively increasing frequency can be used to project the feeling of increasing urgency. For example, the "Cyberlite" system used in a pilot study with taxicabs utilized a rear center-mounted flashing light of 1200 candelas intensity, whose flash frequency varied directly with the force applied to the brake pedal (Goldrath, 1972). The frequencies varied from 1 to 7.6 flashes per second. Pilot use of this light appeared to greatly reduce the incidence of collisions in which the taxicab was rearended.

Hopkins and Holmstrom (1975) concluded that the most desirable frequency should be approximately two flashes per second with 90 per minute the minimum and three to four per second the practical maximum. This indicates a median rate of 150 per minute, which is more than three times the rate presently recommended by AAR.

3.1.2.6 Flash Duration

Little hard data exist regarding the most appropriate on/off ratios (duty cycle) to use. Gerathewohl (1953) found that reaction time decreases with increasing flash duration, within limits, for low contrast conditions. However, Hopkins and Holmstrom (1975) state that "the alerting effectiveness (and distinctiveness) of flashing lights increase as flash duration decreases (for constant radiated energy), down to durations of approximately 0.1 second." They further state that a duration of 0.1 second or less is a basic objective of any improved crossing warning. Assuming their recommended frequency of two flashes per second mentioned in the previous section, this would mean an on/off flash ratio of approximately 1 to 5 (or 20%) or less. They feel so strongly about this that they refer to short flash duration as the "key" to a meaningful improvement in warning lights, and go on to espouse the use of strobe lights (high intensity, short flash duration lights).

Many authors have discussed the desirability of using strobe lights to increase safety in various situations. Wilburn (1975) describes a "halo light," i.e., a flashing white ring surrounding a red traffic signal, which brought about an improvement in accident experience at a problem intersection. Russell (1974) found that the addition of strobe lights to 12-inch* flashers and gate arms at a crossing made the entire system more visible. Hopkins & Newfell (1975) used xenon strobe lights on locomotives to improve their visibility with positive results, as had been suggested by Aurelius and Korobow (1971). Colombre (1974) also reported strobe lights superior to standard flashing beacons for this purpose.

Based upon the review of the literature there appeared to be sufficient reason to further investigate the potential advantages of incorporating strobe lights into the grade crossing warning systems.

3.1.2.7 Size

The issue of size is a relatively uncontroversial one. The trend in traffic signals has been towards using 12-inch* signals to replace the traditional 8-inch* size. There is ample evidence that this change has been an improvement. King, et al. (1975) found installation of the 12-inch* lenses not only reduced accidents but produced a smoother traffic flow. Russell (1974) found that 12-inch* flashers produce slower approach speeds in motorists as compared with 8-inch* flashers. Van den Braden, et al. (1967), using accident data, field studies and simulator research results, also found 12-inch* flashers to be superior to the 8-inch* size.

3.1.2.8 Light Numbers (Redundancy)

The number of signal lights used will influence the effectiveness of the warning system, depending heavily on the placement of the lights. That is, a close cluster of lights may result in a net

* 12 inches = 30.5 cm
8 inches = 20.3 cm

increase in intensity, but can be missed if the driver is not looking in the right direction. Placing the lights in more than one location produces a redundancy that can be of critical importance, especially in traffic situations where other vehicles may block portions of the view.

Redundancy as a means of enhancing perception has been studied by a number of researchers. Dahlstedt (1974) reported that the reaction time for a change from a flashing traffic signal to a steady one was shortened if the change was emphasized by a (redundant) extra light which flashed just at the time of the change. Plummer, et al. (1974) reported that brake reaction times decreased with the addition of reinforcing stimuli, both visual and auditory. McCain (1973) discusses the value of redundancy, especially when there is visual noise and competing stimuli. King, et al. (1975) found that the use of multiple overhead signal installations at intersections improved operational effectiveness. Within limits, then, it would appear that the probability of detection improves with the use of additional signal indications. (However, in certain roadway geometries, extra lights could cause confusion due to parallax, making positioning critical.)

3.1.2.9 Placement

The placement of warning signals is one of the most critical variables influencing the probability of their detection. The trend towards cantilevered signals that are closer to the driver's line of sight is recognition of this fact. Van den Branden, et al. (1967), reported that placing flashers over the center of each lane improves their effectiveness, and King, et al. (1975), assert that a combination of post-mounted and cantilevered signals produced the highest level of operational effectiveness.

King, et al. (1975) suggest from their research that warning devices should be placed so as to fall within a visual angle of 10° as measured from the driver's eyes, rather than the 20° specified in Figure 4-2 of the Manual of Uniform Traffic Control Devices (1971). The purpose of this, of course, is to increase the probability that the signal will be seen by putting it closer to the line of sight.

3.1.3 Driver Behavior at Crossings

While much has been written in recent years on the problem of railroad-highway grade crossing safety, most of the material published has been theoretical in nature or has addressed the issue from the standpoint of economics or technology or has merely represented an exposition of the problem backed up by voluminous statistics.

Only a few studies have addressed the problem experimentally, and from the point of view of the driver's perceptions of grade crossings and his reactions to these perceptions. As a matter of fact, Russell (1974) cites only three studies (prior to his own) that he considers "basic research on driver reaction to grade crossings." These include the studies by Sanders (1972), Sanders, Kolsrud and Berger (1973) and Butcher (1973).

The report by Sanders (1972) describes the results of a study of the behavior of motorists in the vicinity of selected railroad grade crossings. A large number of speed profile measurements were taken that showed that motorists reduce their speed sooner and to a greater extent at crossings that have passive warning devices than at crossings with train activated devices. This difference appeared to be proportionately less in rural locations than it was in urban areas.

The study by Sanders, et al. (1973) was undertaken in support of a subsequent evaluation of alternative grade crossing accident countermeasures. Drivers were interviewed after negotiating a crossing, and their responses were compared with their previously-observed behavior while making the crossing. It was concluded from this that driver looking behavior, crossing speed and speed reduction were valid measures for use in subsequent evaluation of proposed changes in the warning devices. These measures were then used to conclude that the use of flashers in place of passive protection caused a higher percentage of drivers to stop. In addition, the Sanders, et al. study investigated causative factors in a number of crossing accidents and concluded that maintenance of warning devices, driver attention, and driver expectancy were precipitating and predisposing factors in accidents. These are general factors, of course, applicable in many types of driving situations.

Butcher (1973) again used speed profile information as a means of inferring driver reaction to the crossing conditions. Using this system, Butcher concluded that drivers involved in grade crossing accidents are singularly inattentive or distracted, and also that drivers approach at slower speeds and decelerate more gradually as the warning system at the crossing provides a stronger stimulus (e.g., as when the activated devices are in operation as opposed to the passive devices only being visible).

The study by Russell (1974) was the follow up to the Butcher study. Together, they present a picture of driver reaction to two different signal systems at a high-speed, high-accident rural grade crossing. This was a before-after study where the crossing was upgraded from old standard flashers to a modern automatic gate installation which included gate-mounted strobe lights. In addition, Russell concluded that:

1) Almost all drivers approach a crossing in a safe manner, implying that mean values of speed and deceleration are weak parameters for evaluating hazards at a grade crossing or the effectiveness of grade crossing warning improvements.

2) Raised gate arms at new installations improve driver advance recognition of the crossing.

3) When the gate is down, or a train is across the track, approach speed is even slower.

4) The gates with strobe lights had the same effect as the train across the road on slowing the average motorist.

5) The approach speed of following vehicles was more influenced by the preceding vehicle than by the signal type.

6) Subjective impressions suggest that the most alerting aspects of the new signal systems are the strobe lights on the gate arms. Russell urges further study of driver reactions to these lights, varying brightness, flash rates and distance of impact, both day and night.

7) Lack of contrast between the train and its background, combined with reduced visual acuity as a function of advanced driver age and a weak warning signal, is hypothesized as being the most likely primary cause of the majority of crossing accidents.

8) The overall impact of the improved warning system (gate plus larger flashers plus strobe lights plus a Marquardt speed predictor) was to cause drivers to approach the crossing at slower speed, indicating they were alerted earlier and more effectively.

Russell acknowledged that the source of the above improvement could not be isolated or traced to any one element of the improved system. He also urges continued research into the visibility and attention attracting properties of warning devices which was of course the object of this project.

4.0 LABORATORY TEST PHASE

The laboratory test phase of the project was primarily conducted in an indoor laboratory and resulted in the development of two improved add-on devices for improving the attention getting property, conspicuity, of active grade crossing warning systems. The devices developed as a result of the indoor laboratory tests were then put through a very brief but necessary driver response evaluation conducted in an outdoor laboratory. A discussion of both the indoor and outdoor laboratory tests follows in succeeding sections.

4.1 Indoor Laboratory Tests

Test plans and procedures were carefully developed to compare observers responses to targets under controlled laboratory conditions. In each day's experiment, nine test subjects were shown 100 to 180 "displays."* Test subjects were housed in a moving "cabin"* simulating an enclosed vehicle. The plan was to compare the test subject's judgements of relative conspicuity of "targets"* with variations in color, flash rate, luminance, size and placement. Each variable was to be tested under "simulated urban" and "simulated rural"* background settings. Furthermore, each variable was to be tested during daylight, dark and daylight fog conditions. If the experiment plan were to study three or four variations of each variable with a like number of each other variable, the number of statistical cells would have been so large that a meaningful data set would have been impossible to acquire. For this reason, a sequential testing approach was used (day-to-day basis) where the first test would compare three or four color variations and analyze the results. "Winners" would then be judiciously selected and "losers" eliminated before proceeding with the next test--comparison of several flash rates. Following selection of two or three color-flashrate combinations as "winners," these winners would be carried on to be tested with several variations of luminance levels. This procedure of selection and elimination proceeded throughout the laboratory experiment.

*See Glossary

Although this procedure left many higher order interactions untested, it enabled the project staff to focus upon a workable number of important combinations. This sequential produce involved daily experiment design decisions to provide sufficient data to support sound conclusions.

4.1.1 Laboratory Facilities

The indoor laboratory work was done in the Federal Aviation Administration (FAA) Low Visibility Research Facility at the Richmond Field Station of the University of California at Berkeley. This building, shown on Figure 1, is 33 feet* wide and 1,000 feet* long. At the higher end of the building rafter height is 36 feet*. The rafter height tapers to 11 feet* at the center or 500 foot* point. The last 500* feet of the building has a constant 11 foot* rafter height.

The building has an asphalt surfaced floor that closely resembles a two-lane roadway. Portions of the ceiling and the walls are covered with translucent panels.

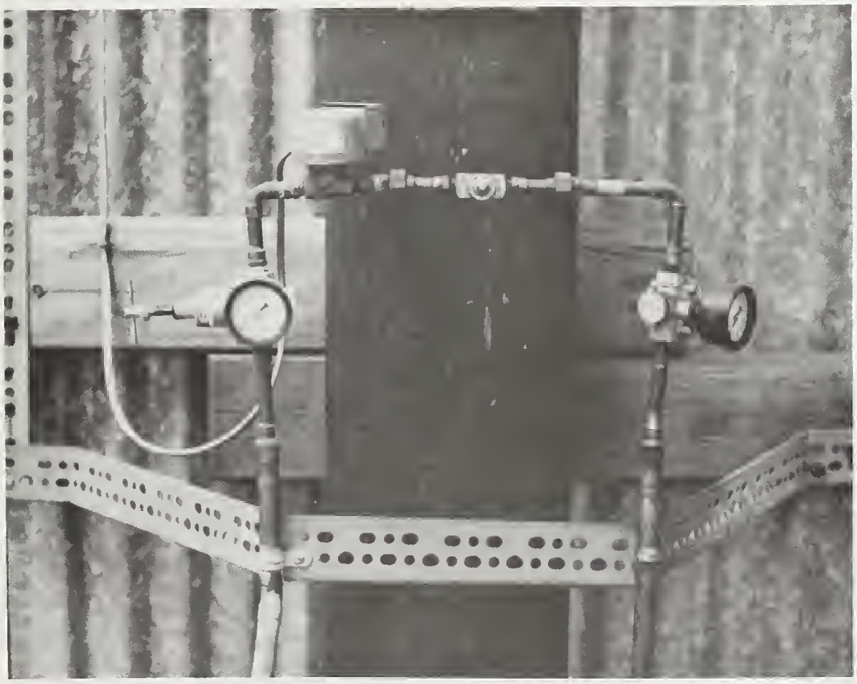
The Low Visibility Laboratory, often called the "Fog Chamber," was designed to generate artifical fog using an atomized water technique. Hundreds of atomizer nozzles like those shown in Figure 2 are located along the rafters and on the walls. Each nozzle is regulated for water pressure and air pressure. Air pressure is generated by four diesel-driven air compressors that supply a total of 2,400 cubic feet* per minute at 100 pounds per square inch*. Remote control solenoid water valves are located adjacent to each atomizer nozzle, as shown in Figure 2. These valves are opened and closed to produce short bursts of atomized water upon remote command.

The 1,000 feet* long building is divided into 24 fog control subsections. Each subsection has its own fog density sensors, as shown in Figure 3. These sensors monitor light transmission or fog density across the subsection. The sensor data is transmitted to a central console. The control electronics at the central console

*33 feet = 10.1 meters
1000 feet = 305 meters
36 feet = 11 meters
11 feet = 3.4 meters
500 feet = 152.5 meters
2400 ft^3 = 68.1 $meters^3$
100 psi = $7X10^5$ Pascals

FIGURE 1
FAA LOW VISIBILITY RESEARCH FACILITY
RICHMOND FIELD STATION
UNIVERSITY OF CALIFORNIA AT BERKELEY

Rafter Mounted Atomizer System



Wall Mounted Atomizer System

FIGURE 2
FOG CHAMBER ATOMIZER SYSTEM

Transmitter

FIGURE 3
FOG DENSITY SENSORS

continually compares the fog density in each subsection with the desired density selected by the console operator. The electronics in the console then signal the water valves in each subsection when to produce a short burst of fog.

All of the low visibility conspicuity related experiments were conducted in 475 foot* visibility fog. The fog density was such that the standard fog target as shown in Figure 4 was clearly visible at 450 feet,* but not visible at 500 feet.* The standard fog target is a 25 watt lighted bulb on a 36-inch* diameter black disk.

The FAA laboratory was originally constructed to simulate the glide path and landing of commercial aircraft. A simulated aircraft control cabin with full controls travels on rails hanging from the rafters.

An 8 feet* by 16 feet* test subject "cabin" was constructed to one side of the aircraft cabin. Exterior views of the test subject cabin are shown in Figure 5. A view of the cabin interior and the test subject's view from the cabin are shown in Figure 6. The size of the cabin and the comfortable seating arrangements provided a relatively pleasant housing for nine test subjects and three test monitors.

As shown in Figure 5, the cabin was built with a 16 feet* wide windshield across the front. The cabin windshield was designed with the same vertical height as the windshield of a "composite" automobile. The windshield was covered by two opaque drop curtains, one hinged at the top and one at the bottom. With the curtains in the ready position, the windshield was completely covered. When the subject cabin moved forward to a location 420 feet* from the displays, a switch was tripped that dropped one curtain, opening the windshield; this curtain position is shown in Figure 5. The switch also started an electronic timer. At the end of the pre-selected time, the second curtain dropped covering the windshield. The curtains were always reset to the ready position, between test presentations, without giving the test subjects a look through the windshield.

*475 feet = 144.9 meters
450 feet = 137.3 meters
36 inches = 91.4 cm
8 feet = 2.4 meters
16 feet = 4.9 meters
420 feet = 128.1 meters
500 feet = 152.5 meters

FIGURE 4
STANDARD FOG TARGET

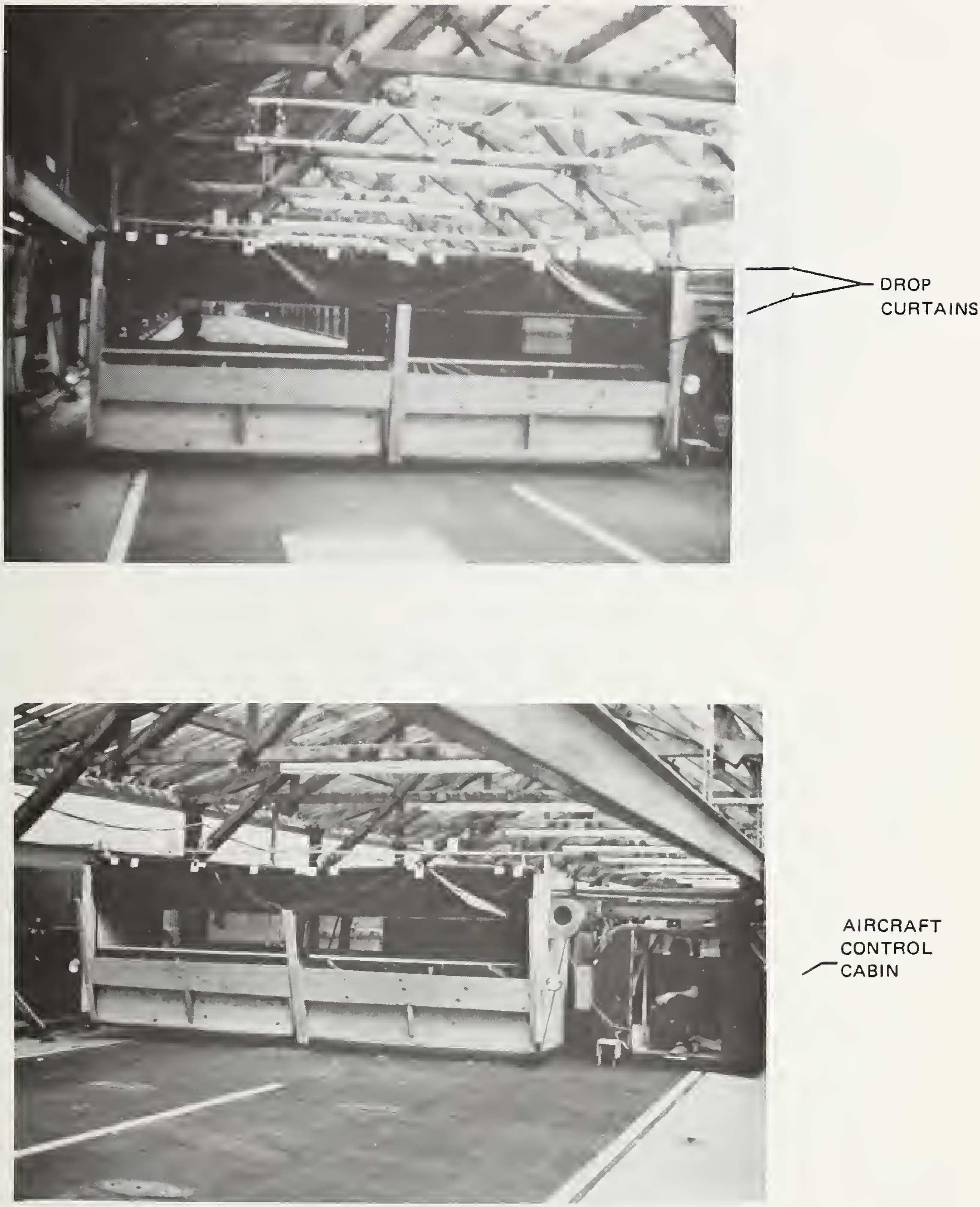


FIGURE 5
MOVABLE TEST SUBJECT CABIN

CABIN INTERIOR

FIGURE 6
VIEW FROM CABIN

Daylight tests were conducted with cabin light levels held well above the comfortable reading level.

Nighttime tests were conducted at a very low light level corresponding to moonlight, lower end of mesopic vision range. At the conclusion of each test presentation, dim cabin lights were turned on for about 30 seconds while test subjects recorded their observations. The cabin interior was still below comfortable reading light level when the cabin lights were on. The cabin was darkened again one to two minutes before the next test presentation began.

4.1.2 Test Subjects

Shoppert's analysis (Ref. 1) of 15,000 train-auto accidents indicated that the automobile drivers involved in those accidents were distributed as follows:

1) About 25 percent under age 25

2) About 20 percent over age 55

3) About 20 percent female and 80 percent male

It was the project team's desire to select daily, nine test subjects along the lines of above age and sex distributions. The California Employment Development Department provided the groups of test subjects to resemble the driver population when considering such factors as education and ethnic background. The Employment Development staff did an outstanding job of furnishing drivers who fit the above specifications. It was most surprising that they found two or three college graduates for each test group. There was also an excellent balance of students, blue collar workers, white collar workers and professional people. Each test subject held a California driver's license and they experienced no color vision problems. Among the 150 test subjects, it was found that only three were not anxious to follow instructions. Each group of test subjects participated in three test sessions--daylight, daylight fog and nighttime conditions. The daily tests began at 3 p.m. and ended about 11 p.m. with a two-hour break for dinner.

4.1.3 Test Session Design

The limited width of the laboratory constrained the number of flashing lights to be presented at one time to three. To intensify the competition for attention, a standard roadway sign was mounted below each pair of lights; thus, a total of six objects were seen, as shown in Figure 7. In each "display,"** only one pair of lights were of primary concern; the other two flashing light pairs and the signs were designated as "decoys."** Each test session was normally composed of 36 to 60 such displays.

The experimental design used for one luminance test day was typical of the other test designs, and is therefore, explained in detail. Thirty-six (36) displays were used in each test session. Three luminance levels were compared using both a red/red pair of 8-inch* flashing lights and a red/blue pair of flashing lights. Each light flashed at 55 flashes per minute with a 50 percent duty cycle. Two typical displays of lights and signs are shown in Figure 7. The three luminance levels were 275 foot-Lamberts,* 550 foot-Lamberts,* and 1,100 foot-Lamberts.* To present a variety of targets to the test subjects, 12 different decoy targets were used in the test. Letting $d_1, d_2, \ldots, d_{12}$ denote each of the twelve distinct decoy targets and r_1 denote the red/red flashing pair at 275 foot-Lamberts.* The triplet (r_1, d_1, d_2) defines a display with the red/red pair of the left, decoy number one in the center and decoy number two on the right, see Figure 7. The r_1 notation denotes not only an 8-inch* pair of reds but also a specific pole mounted sign. Likewise d_1 and d_2 also indicate a specific pair of flashing lights (not red/red nor red/blue) as well as their associated pole mounted signs.

* 1 foot-Lambert = 3.426259 candelas/meter^2
8 inches = 20.3 cm

** See Glossary

FIGURE 7
TYPICAL FLASHING LIGHT AND SIGN DISPLAYS

Remembering that r_1, r_2 and r_3 are red-reds at three luminance levels - and rb_1, rb_2, rb_3 are red/blues at the same three levels, six displays were arranged as follows:

#1 = r_1, d_1, d_2

#2 = r_2, d_1, d_2

#3 = r_3, d_1, d_2

#4 = rb_1, d_1, d_2

#5 = rb_2, d_1, d_2

#6 = rb_3, d_1, d_2

These six displays were identical in every respect except for the color and luminance level of the flashing lights to the far left. Substituting the two decoys d_3 and d_4 for d_1 and d_2 and additional six distinct displays, a total of twelve are defined where each display had a red/red or red/blue flashing pair located to the far left of the display and decoys positioned in the center and far right target location.

In similar fashion, twelve more distinct displays were designed with primary targets r_1, r_2, r_3, rb_1, rb_2 and rb_3 in the center position. Decoys d_5, d_6, d_7 and d_8 were located to the left and right. The final twelve displays naturally follow where r_1, r_2, r_3, rb_1, rb_2 and rb_3 are located to the far right and decoys d_9, d_{10}, d_{11}, and d_{12} are located to the far left and center positions in the displays.

In summary, there were six displays at each luminance level for both the red/red and red/blue flashing pairs, or summing the red/red and red/blue pairs, a total of twelve displays at each luminance level. Using nine test subjects times twelve displays results in 108 test subject exposures to displays containing either a red/red or red/blue pair at each luminance level.

Each of the 36 luminance test displays were numbered and assigned a randomized order of presentation. Three different randomized presentation sequences were employed for the three daily test sessions, daylight, daylight-fog and nighttime.

4.1.4 Test Subject Management

Each group of test subjects were used for three sessions on one day. The day began in early afternoon with about 45 minutes of explanation and instructions for conduct of the test. These instructions included:

1) Subjects were told that the tests involved finding ways to improve some particular highway safety devices with which they were all familiar.

2) They were told exactly what colors and what signs they would see to choose from. This minimized the temporary novelty effect of some of the "hard to read" signs until a subject had once identified them. Since all displays were presented at 420 feet*, a few test subjects had difficulty reading certain word messages.

3) Test instructors and monitors carefully avoided mention of railroads or railroad signals so that the test subjects would be unaware that there may be study emphasis on flashing red lights. Most test sessions designs were such that the frequency of appearance of red pairs of lights did not suggest such conclusions on the part of test subjects.

4) Each test subject was given a loose leaf notebook. They were asked to record their response to each display in one, two or three words such as:

   Red - Red Lights
   Stop Sign

---

* 420 feet = 128.1 meters

Yellow - Yellow
One Way
Green - Blue Lights

One page was used for recording the subject's response to one display. The subjects were asked to never look back to results of prior displays once they had recorded their responses and turned a page.

5) Test subjects were always asked to refrain from discussing the displays and particularly from commenting on what they saw or did not see.

6) Instructors and monitors were careful to be very pleasant and friendly with the test subjects. It was believed that the results of the test would be most valid when obtained in a comfortable, pleasant, friendly and relaxed atmosphere.

7) Test subjects were asked to choose a "winner" (their choice) among the six devices in each display. Most often, they were asked to write down which device held their attention the longest portion of the 4-1/2 second display period. They were asked not to guess. If it was not clear in their own mind that one device stood out, they were asked to record a "?." For some test variables, a 1-1/2 second display period was used. In this case, subjects were asked to identify the device that captured their attention first. This was not appropriate for all variables, e.g., when flash rates were varied. As one would expect, a 1-1/2 second display does not shown enough flashes for one to discriminate between flash rates ranging from 60 to 120 flashes per minute. Depending upon the variable that was being tested, the display time was either 1-1/2 or 4-1/2 seconds as determined by trial work using subjects not included in the data.

During the first two days testing, test subjects were requested to record simply "what they saw." When analyzing the results, it was clearly apparent that most people accepted this as a challenge to their capacity to see and memorize. The results were just what one with hindsight might predict. Most people read across the scene, left to right, top to bottom. This is precisely the order that most people learn to read and memorize. The results proved to be useless.

On the third test day, the subjects were asked to record only two of the devices they observed. After examining the results, it was quite clear that the left display position was still favored, however, with only little preference over the center and right display position (see Figure 7). It was therefore concluded that asking the test subjects to record more than one device (which either caught or held their attention) would introduce display position bias in the results.

On the fourth day, the subjects were asked for a single "winner." An analysis of these responses gave no indication of position bias. Throughout the remainder of the test this technique (subject choice of a single target) was retained with occasional spot checks for possible position favoritism. No further evidence of position bias occured.

4.1.5 Incandescent Displays

Two typical displays as seen by the test subjects are shown on Figure 7. The flashing lights and the signs were mounted on a movable standard, see Figure 8. Each standard was equipped with a flash rate and luminance controller as shown in Figure 9. The flash rate controller was designed and constructed so that any of five flash rates (40/min., 55/min., 70/min., 90/min., 120/min.) could be selected by changing a selector switch. The luminance controller consisted of eight separate light control circuits, four for each light of a pair. A double-pole, four-position rotary selector switch was wired to the four light control circuits as shown on Figure 10. Prior to subject testing, lights were individually preset at desired luminance levels with a photometer by adjusting the

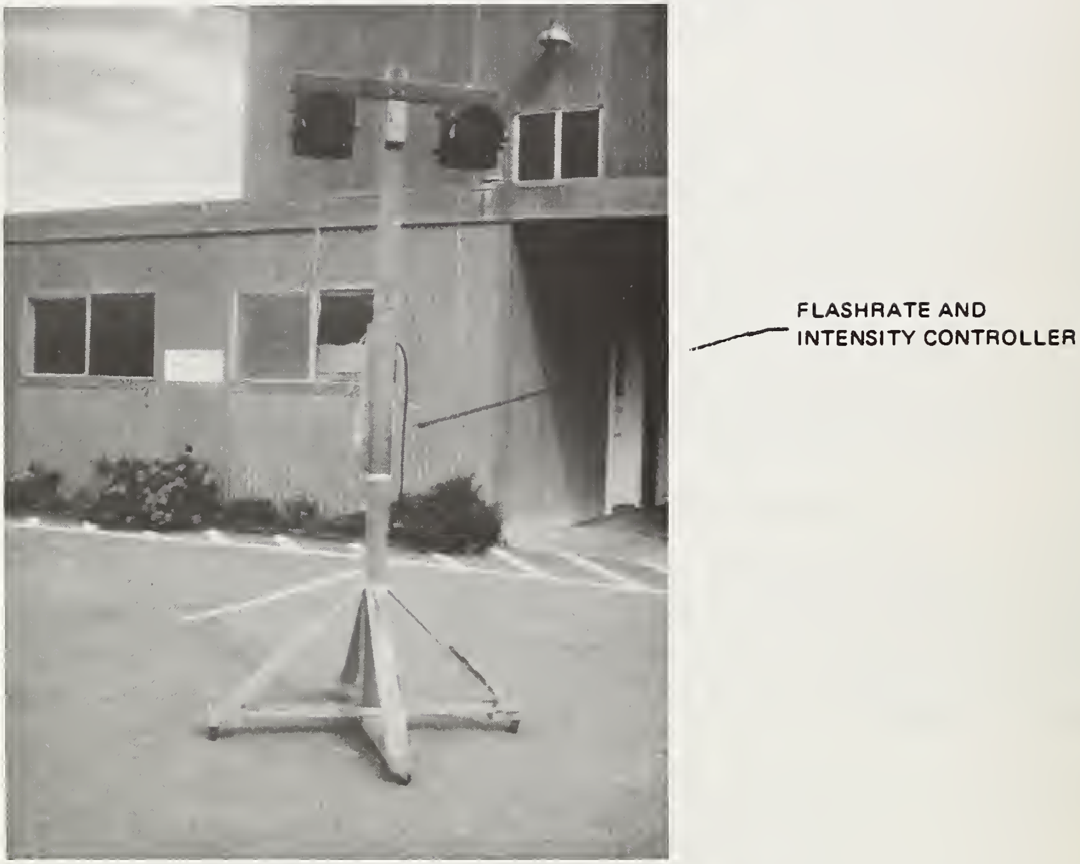


FIGURE 8
MOVABLE STANDARD

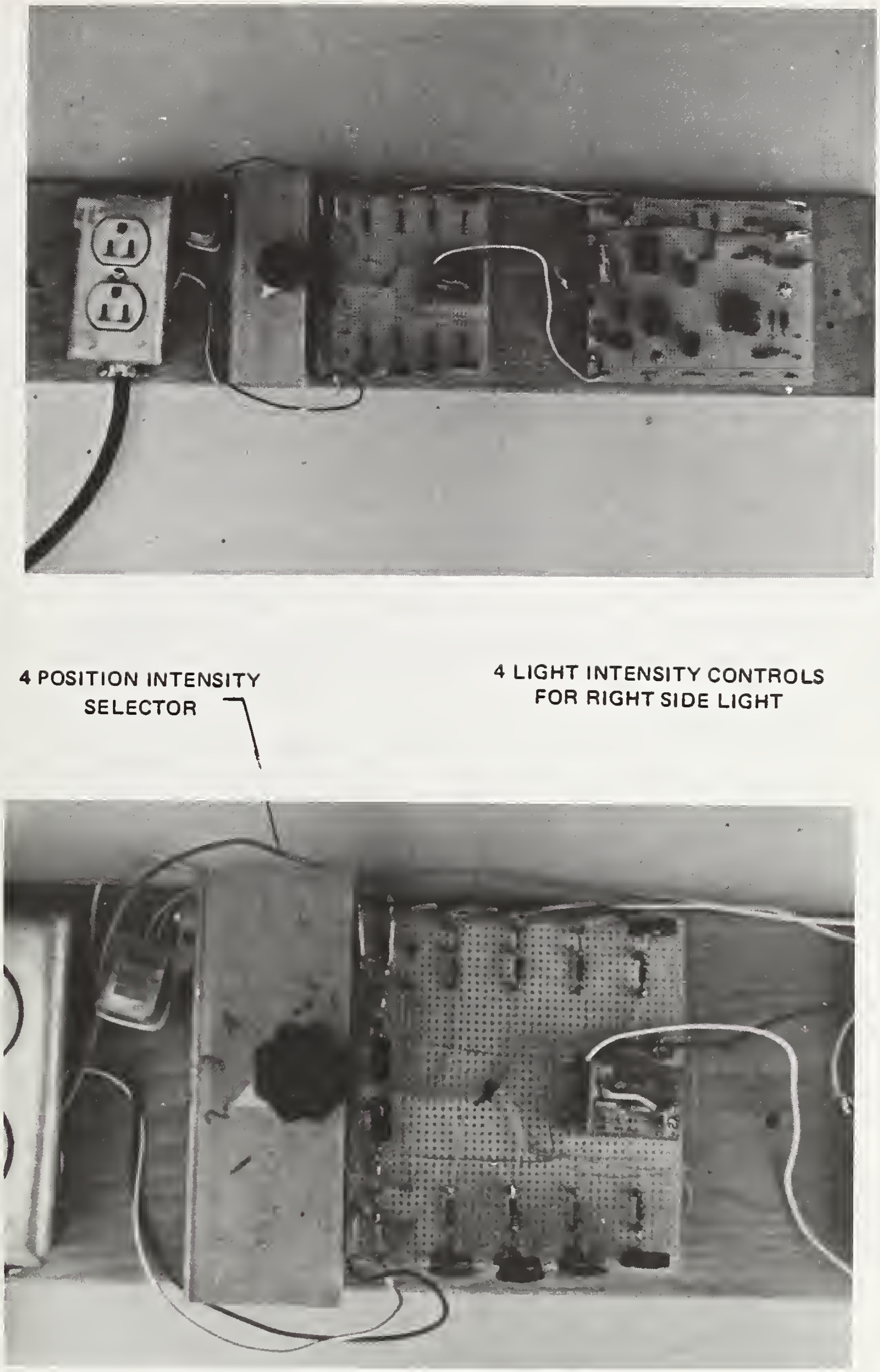


FIGURE 9
FLASHING LIGHT CONTROLLERS

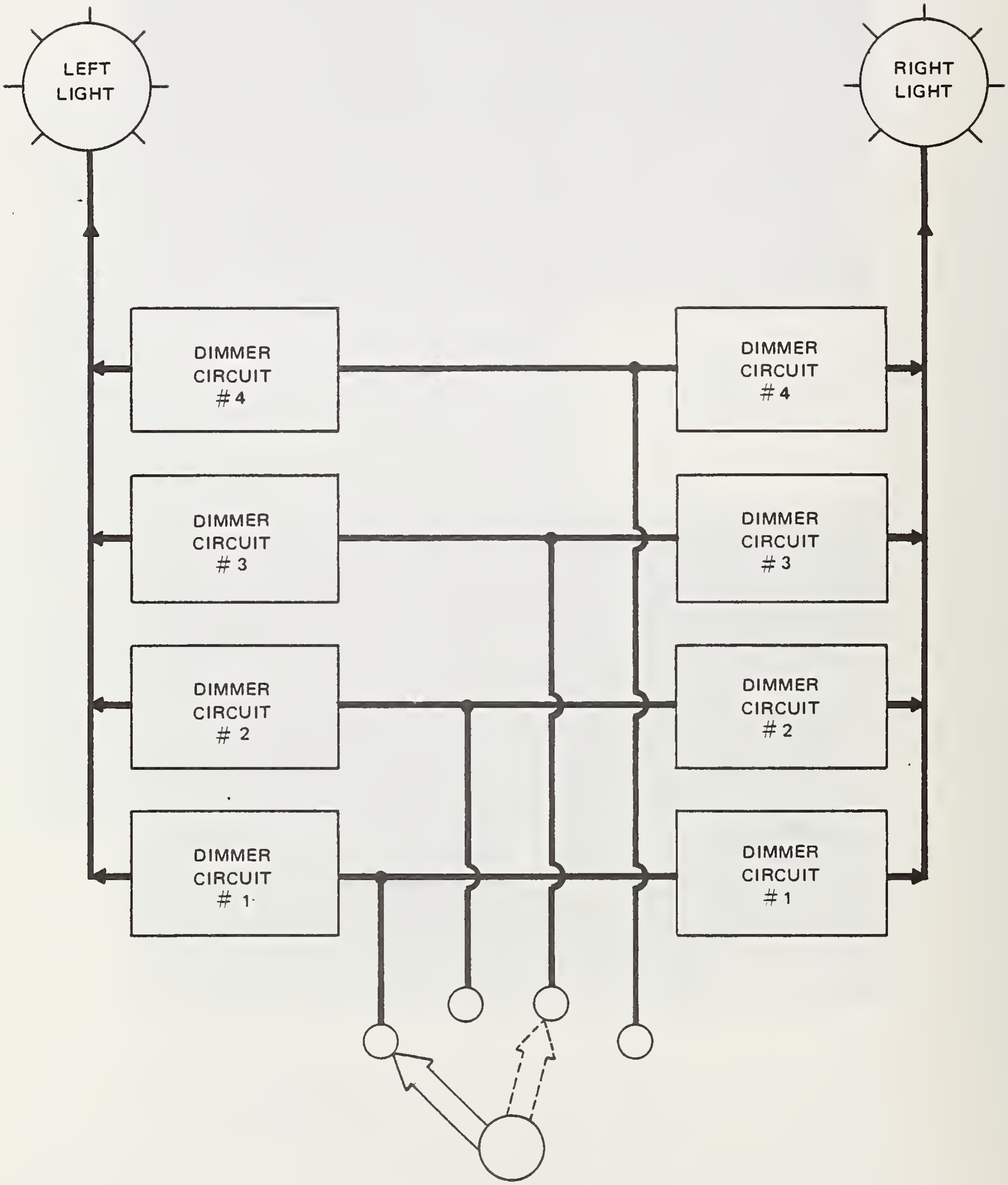


FIGURE 10
ROTARY SELECTOR SWITCH

light control circuits, and the selector switch, corresponding to a pair of light control circuits. The four-position selector knob was used by test personnel to quickly change a pair of lights to a desired luminance level. This control system facilitated rapid change of light and sign displays between test subject exposures.

The photometer was a Model 2020, manufactured by Gamma Scientific Instruments. The photometer and its standard calibration light source were factory calibrated to ± five percent accuracy. The photometer color sensitivity across the visible spectrum closely approximates that of the human eye under daylight conditions.

During the first three test days, it became evident that the mechanics of presenting 36 to 60 displays must take no longer than one and one-half hours. When scene changes and new presentations were made in one and one-half to two minute intervals, the test subjects displayed keen interest in the experiment. When the test personnel were ill prepared, experienced equipment breakdowns or, for other reasons, allowed the test session to move slowly, the test subjects lost some of their interest and their attention wavered. Therefore, all mechanical and electronic equipment was designed to reduce the display change time to an absolute minimum. The light standards were constructed on large rubber tire casters so they could be moved in and out of position in a few seconds.

During all test sessions simulating a high contrast, noncompetitive rural highway condition, the displays were presented with a neutral, camouflage background as shown in Figure 7. When simulating urban background conditions, the camouflage curtains were removed. City street background clutter was added using additional highway signs, street lights, pedestrians, advertising signs, automobiles and opposing headlights.

4.1.6 Indoor Laboratory Test Results

The summary results of laboratory tests are presented in the following sections. A detailed discussion is contained in Appendix D.

4.1.6.1 Color Test Conclusions

Based on data from two test groups, the following conclusions are made across daylight, daylight fog and nighttime conditions when comparing pairs of alternately incandescent flashing lights, when size, flashrates and luminance levels are equal:

1) No evidence of significant difference was found in conspicuity of red-red, red-blue, and blue-blue.
2) The orange-orange pair was significantly less attractive than the red-red, red-blue or blue-blue, in daytime and nighttime lighting conditions.

Other significant observations (not all statistically significant) were as follows:

1) The orange-orange flashing light pair although a very poor fourth choice, out of four, in daylight and nighttime was the first choice in daylight fog (test group 1). This is explainable in theory relative to blue but not for red, unless people associate orange (near amber) with fog lights.
2) The daytime to nighttime eye sensitivity shift from red to blue is seen in comparing the red-red flashing pair to the blue-blue flashing lights (test group 1).
3) The red to blue shift was not seen in test group two. This may well be due to the use of far more competitive decoy targets in the second test as well as using the same daytime and nighttime primary target luminance levels, i.e., the shift may become pronounced at lower luminance levels.

4) The 1-1/2 second exposure time may well have been too short to comprehend flashing light pairs at 55 flashes/minute.

4.1.6.2 Flash Rate Test Conclusions

After testing three groups of subjects across five flash rates, using two colors and three luminance levels for alternately flashing light pairs, it was concluded:

1) Prior research concerning conspicuity of single flashing lights may not apply to bright, alternately flashing pairs at flash rates ranging from 60-120 cycles per minute.

2) There is no evidence of difference in conspicuity between flash rates ranging from 55-90 cycles per minute.

3) Flash rates ranging from 55-90 cycles per minute offer greater conspicuity than slower or faster flashrates.

It is important to recognize the above conclusions apply only to:

1) Incandescent powered lights,

and

2) Alternating flashing light pairs with 50 percent duty cycle where no low level filament voltage is maintained on the lights during the "off" portion of their duty cycle.

As will be seen in section 4.1.6.7, the above conclusions drastically change when flash rate testing is done with xenon flash tubes as the light sources.

4.1.6.3 Luminance Test Conclusions

Three test groups provided data comparing "luminance"* of alternately flashing pairs under rural highway simulation conditions. Primary targets were presented across two color combinations, two flash rates, and two sizes of signal heads. It was concluded that

- There is strong interaction between light source luminance levels, background contrast and eye threshold detection levels as well as the eye's ability to discriminate between the luminance levels of radiating light sources. Hence, where the eye may be logarithmic in response to brightness change in the light source, against a bright background, this is no universal condition.
- The eye is very sensitive and discriminatory to doubling of luminance, at those levels tested, when the emanating source is near detection threshold, i.e., in a fog condition.
- Nighttime luminance discrimination in the lack of background clutter (other lights) is poor at those levels tested, i.e., the eye may be saturated and it will take considerable brightness changes to perform discrimination.

4.1.6.4 Size Test Conclusions

The subject of size, 8-inch** versus 12-inch,** cannot be separated from luminance. In going from an 8-inch** head to a 12-inch** head, the light source power is normally increased to retain equivalent luminance, even though there is some improvement in the light collection efficiency of the larger head. There were two strictly size/luminance tests conducted. The second of these tests produced some inconsistent results.

Based on the luminance levels tested, a 12-inch** pair of flashing lights tested far better than a brighter pair of 8-inch** flashing lights in a noncompetitive background. Considering the decoy

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*See Glossary

** 8 inches = 20.3 cm
12 inches = 30.5 cm

set of lights as competition (not background) a change in light size with some increase in luminance has far more payoff potential than a strict increase in luminance in "overcoming" the decoy set (all those competing light arrangements).

There is still much to be answered relative to size, particularly where there is a lot of background clutter.

It should be noted that at 450 feet,* without intervening visibility restrictions and with 10-12 feet* separating 8-inch* and 12-inch* heads, size difference is not difficult to see, in fact the two heads are "boldly" different in size.

4.1.6.5 Placement Test Conclusions

Two placement tests were conducted and both suffered problems with consistency of explainable results. Regardless of this lack of consistency, however, a top center flashing pair location (cantilevered pair) and a lower right position (typical side of road pole mounting) constantly were preferred by test subjects over a "high-right" position mounting. This conclusion is, of course, based on unobstructed view of all three placement positions.

4.1.6.6 Red and Blue Strobe Conclusions

Much to the surprise of the researchers, the red pair of flashing strobe lights did not fair well against an 8-inch* pair of narrow beam, 18 watt (reflectorized bulb) incandescent powered railroad flashing red lights. Strobe power consumption per flash and maximum flashrate tested were 17 Joules and 110 cycles per minute, respectively. The railroad flashing lights were viewed within a few degrees of beam center.

The second group of test subjects compared the same railroad flashing pairs to red-blue flashing strobe pairs. The results shifted in favor of the 17 Joule red-blue strobes at a flash rate of 220 cycles per minute (likely due to the blue color and the

* 450 feet = 137.3 meters
10 feet = 3.1 meters
12 feet = 3.7 meters
8 inches = 20.3 cm
12 inches = 30.5 cm

spectral wavelength energy distribution of the xenon tube). Outside of wider beam width's associated with strobes, the red-blue strobe could be considered only an incremental improvement. It is presumed, without much risk, that a blue-blue strobe test, if it had been conducted would likely have produced another incremental improvement.

4.1.6.7 Novel Flashing Light Conclusions

The work on novel flashing lights was a bold step in color/intensity testing. Fashioned from previous observation of incremental improvements, at the best, and the basic theory of color vision a set of three full scale tests were conducted of a selected cross section of white strobes and other novel devices. Following these tests, it was concluded that:

1) White strobes are far more effective than colored strobes when supplementing standard railroad flashing pairs.

2) Redundancy (multiple strobes) is important to conspicuity in all daylight conditions and in darkness when displayed with a competitive background.

3) Doubling the strobe intensity improves conspicuity in daylight and at night with competitive backgrounds.

4) Flash rates exceeding 100 per minute are significantly more effective than slower rates.

4.1.6.8 Gate Arm Test Conclusions

After large-sample tests of six different combinations of gate arm reflectorization, lighting, and signs, the test response data indicates:

1) Gate arms using conventional reflective sheeting and those using red and white paint with a 3-inch* diameter retro-reflectors in each color panel showed no difference in conspicuity.

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* 3 inches = 7.6 cm

2) White and blue strobe lights replacing the conventional flashing incandescent red lights significantly improved conspicuity of the gates.

3) A red strobe light did not improve conspicuity of the gate arms.

4.2 Outdoor Laboratory

The project work plan included outdoor laboratory testing following the indoor laboratory testing. The outdoor laboratory tests were designed to take a further look at those devices that indicated greater driver attention getting properties than conventional equipment. The intended purpose of the outdoor laboratory test was to confirm the findings of the indoor laboratory test and to assure that new and different devices would not result in adverse driver behavior when tested at actual grade crossing locations.

Findings and conclusions from the indoor laboratory tests clearly indicated that white (clear) xenon strobe lights offered the most promise for improving conspicuity of gates and active flashing lights. The evidence leading to these conclusions was so emphatic that confirmation in the outdoor laboratory seemed unnecessary. However, there was a possibility that these more powerful lights might startle or frighten some drivers.

4.2.1 Driver Response Tests

The outdoor laboratory tests were conducted in Camp Parks, a government owned military facility nearly devoid of any activity, with only a small operations staff located on the base itself.

Figure 11 shows the view of the simulated crossing where the triple white strobe add-on device, was tested for subject driver response. Figure 12 shows the 8-inch* railroad pair of heads with the triple white strobes mounted 30 inches* above the red pair of lights. At this point of the project the primary goal of the project team was to ascertain whether or not the novel, multiple white strobes would cause any erratic behavior when presented to the unsuspecting

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*8 inches = 20.3 cm
30 inches = 76.2 cm

FIGURE 11
SIMULATED CROSSING (CAMP PARKS)

FIGURE 12
CLOSE-UP VIEW/SIMULATED CROSSING

driver. Nighttime was considered far more critical than daytime. Since the backplates on the lights serve little or no purpose at night, they were not used in the Camp Packs tests (backplates were used in the field installation, see Figure 16, section 5). The roadway in this area of Camp Parks simulates a rural two lane road with very little side friction. The approach tangent was long enough for drivers to comfortably reach 45-50 mph* prior to signal activation. With each test subject, signals were activated when the vehicle was 200 feet* from the normal stop position. Through trial and error, staff members judged that activation at this point would require an instant decision and keen driving skills to make a reasonable stop without overshooting the signals. The red flashers and the strobes on the driver's right were aimed to emit maximum brillance when the driver was 375 to 400 feet* from the signals.

Figure 13 and 14 show an actual spur crossing in Camp Parks where test subjects were exposed to the red, white and blue gate arm mounted strobes as tested in the indoor laboratory. The two standard flashing incandescent lights on the gate arm were replaced with white and blue strobe lights. The crossing was located approximately 350 feet* from a blind curve (to the right). The Camp Parks streets in this general area were normally driven at 20-30 mph*. The gate location simulated an urban city street crossing. With each test subject, signals were activated as soon as drivers rounded the roadway curve and came into view of the gates. Activiation at this point of the driver's approach gave them ample time to perceive, and react to the signals, i.e., come to a smooth stop before reaching the lowered gate.

Three drivers were tested in a mid-afternoon test session. Each driver was directed along a five mile* course around Camp Parks before arriving on the scene of the simulated rural crossing. In each case, the observer directing the test driver was able to gain the driver's confidence and make him feel at ease with the situation. Within 2 or 3 minutes of driving time, each driver became fairly relaxed and appeared to be functioning in a normal manner.

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* 1 mph = 1.6 km/hr 1 mile = 1.6 km 1 foot = .3 meters

FIGURE 13
GATE PROTECTED CROSSING /GATE DOWN

FIGURE 14
GATE PROTECTED CROSSING (CAMP PARKS)

When approaching the rural simulated signal, each driver was encouraged to travel at 45-50 mph* as soon as they entered the tangent roadway section approaching the signal. None of the three drivers showed any distress upon activation of the signal. Each reacted in a perfectly normal manner and came to a stop as smoothly as could be expected. Each was a little surprised after a few seconds afterthought because all know full well there were no railroad trains traveling through Camp Parks. After another two* or three* miles of driving, the test drivers were taken around the curve on the approach to the simulated urban crossing with gates. No drivers showed any signs of distress or surprise when these signals were activated, and the gates were lowered. All drivers came to a stop in a desirable manner.

After dark, on the evening of the same day, identical tests were repeated with four drivers on the same routes through Camp Parks. The only difference between the morning and afternoon was that it was very difficult to reach the 45-50 mph* speeds upon the approach to the rural simulated signal. Most drivers were conservative when they found themselves on strange roadways in total darkness. They were reluctant to reach the desired speeds. When the lights were activated at the simulated crossing, each driver reacted exactly as had been hoped. No driver showed any signs of great surprise or distress. Similar reactions occurred when all drivers rounded the curve approaching the drop gates. Upon activation, no driver showed any distress as they came to a smooth stop.

Upon completion of these tests, it was concluded that there was no reason that the 8-inch* strobes or the smaller strobes on drop gates should not be field tested. No driver committed any act that would cause concern relative to driver response to a field installation of these same devices.

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* 2 miles = 3.2 km
3 miles = 4.8 km
8 inches = 20.3 cm
45 mph = 72 km/hr
50 mph = 80 km/hr

5.0 FIELD TEST PHASE

The work plan for conduct of the project called for field testing of two improved attention-getting devices, flashing light combinations or arrays, which could be used in addition to those devices already installed at existing activated crossings.

With conclusion of the laboratory work, the results indicated that a white, multiple head, 8-inch* white strobe light configuration showed most promise for an add-on device to a flasher protected crossing.

Development of the add-on device for gate protected crossings focused only on the gate arm itself since the 8-inch* strobe configuration could be added to the crossing installation, if the fundamental accident or gate damage problem of a specific location did not lie with the conspicuity of gates themselves.

With cooperation of the Santa Fe Railroad, the California Department of Transportation, the California Public Utilities Commission, and the Federal Highway Administration, two Santa Fe railroad crossing locations were chosen for installation and field testing of the improved devices.

A discussion of these devices, the two field test sites and the data collection and analysis follows in succeeding sections.

5.1 Standard Avenue Crossing

The field test site for installation of the white (clear) 8-inch* strobes is known as the Standard Avenue Crossing. Its location is Richmond, California on State Highway 17 (also Standard Avenue). At this location, State Highway 17 is a six-lane traffic signalized arterial with traffic speeds in the 35-40 mph* range or higher in the off peak period. Traffic speeds in the peak periods are controlled by heavy vehicle volumes and a number of traffic signals as well as the Standard Avenue train crossing signal. One, closely located, traffic signal is 340 feet* south of the crossing and operates independently of the Santa Fe's crossing warning system (see Figure 15). To the west of the crossing, top of Figure 15, is the Santa Fe's switching yards.

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* 8 inches = 20.3 cm
340 feet = 103.7 meters

35 mph = 56 km/hr
40 mph = 64 km/hr

FIGURE 15
STANDARD AVENUE CROSSING

5.1.1 Accident History

The twelve (12) year accident history, provided by the California Public Utilities Commission (PUC) reveals 28 vehicle/train accidents from 1965-1976, inclusive. The breakdown of these accidents show:

1) One: train hitting a parked vehicle.
2) Two: daytime vehicle/train accidents.
3) Two: indeterminent (daytime or nighttime) vehicle/train accidents.
4) Twenty-three nighttime accidents.

Of the twenty-three (23) nighttime vehicle/train accidents, twelve (12) are noted as the vehicle hitting the train and eleven (11) are noted as the train hitting the vehicle. Of the twelve (12) nighttime vehicles hitting the train, only two (2) are noted as hitting units behind the locomotive (6th and 15th units behind the locomotive). Based on the data, twenty-one of the twenty-three nighttime vehicle train accidents were "collision course" (locomotive and vehicle) with either the locomotive or vehicle arriving first.

Based upon lengthy observation of this grade crossing (present plans are to begin grade separation construction with in 2-3 years), the daytime vehicle driver behavior at this crossing is characterized as a "game of chicken" (a common view shared by those familiar with vehicle driver behavior at the crossing) where hurried drivers endeavor not to be delayed by lengthy train switching movements. This behavior (observed to much lesser degree at other flasher protected crossings) is magnified by a vehicle average daily traffic of approximately 25,000 vehicles coupled with daily train activation of the crossing signals which may run as high as 75-100. The crossing, being located at the west end of the Santa Fe's switching yards, may be occupied by a train for considerable time (in peak traffic periods), though prohibited by law to be no longer than 10 minutes duration.

The previous mentioned risky driver behavior during daytime apparently causes little accident problems (during daytime) since of the two daytime (for certain) accidents, only one might be attributable to this behavior (the other involved a vehicle hitting the ninth unit of the train). This type of behavior is likely worse at this location than most other active, flasher protected crossings, however, based on the comments of numerous contacts made during this study, running (failing to stop) the flashing lights, or "beating" the lowering of a gate arm is not an uncommon driver behavior. A gnawing feeling arises if one considers this risky behavior, (coupled with a lack of enforcement of the stop rule at active crossings) and ponders how much carryover there is in nighttime driver behavior, when visibility is greatly reduced and the train itself is an inconspicuous target. If faced with the same threat of penalty for running an active crossings as for running a red traffic signal, the question arises as to how many nighttime vehicle/train accidents could have been eliminated at Standard Avenue over the past 12 years if those who saw, could have stopped--didn't, and would have had a better chance of seeing the oncoming train (whose speeds rarely exceed 10 mph* at this location) if they had stopped?

5.1.2 Strobe Light Controllers

The triple white, 8-inch* strobe light configuration and its placement over a pair of 8-inch* red railroad flashing lights was shown in Figure 12 (without backplates). Within each 8-inch* head is mounted a sealed beam xenon flash tube which concentrates 50 percent of the light output into a 15° cone around the beam center.

Basic power was 110V AC. Two 12V DC signals were also fed to the controller, one signalled activation of the Santa Fe's motion detector circuit and the other sensed the island (occupancy) signal, i.e., when track circuitry sensed some portion of the train occupied the crossing. An option existed as to whether the strobes, triggered by the motion signal, would or would not operate with the

* 10 mph = 16 km/hr
8 inches = 20.3 cm

island signal; the latter was chosen. Hindsight and local conditions indicate the strobes at the Standard Avenue location should always operate as long as the red warning lights are activated.

The light flash pattern was always the same; right side, center, left side, center, right side, etc.. The flashrate was selectible via one set of rocker switches which controlled the time between flashes of the outside pair. This time varied from 200-500 ms (milliseconds) in 50 ms increments. A second set of rocker switches controlled the time interval between an outside light flash and the center flash. This time interval was 50-200 ms in 50 ms increments.

The energy discharge per light flash was selectible at 2.8, 5.6, 8.4 and 11.2 Joules. One energy level was selected as nighttime, the second as daytime and a photo cell controlled the daytime darkness switching between the two levels.

5.1.3 Strobe Unit Installation

Installation of the two strobe units and their controllers are shown in Figure 16. The controller cabinets are mounted on the catwalk behind the strobe heads themselves. The lights were turned on 1 April 1977 and operated unattended through 19 July 1977. The flashrate on the outer pair of the triple heads was 120 per minute, while the center light trailed the flash of each outside light by 50 ms. The selected energy discharge per flash was an extremely conservative value of 2.8 Joules nighttime and 5.6 Joules daytime. Cylindrical 8-inch* shields were mounted on each strobe head so as to confine or direct the light to oncoming traffic as much as possible. The strobe units facing north were aligned, center beam, approximately 1,000* feet upstream, at which point the roadway curved to the west. To the south, the heads were tilted downward so as not to interfere with drivers approaching the traffic signal 340* feet to the south.

5.1.4 Data Collection

A 16 mm camera, with telephoto lens, was used to gather time lapse data, one frame per second. Located on a hillside 1,500* feet southwest of the crossing, the lens was zoomed to cover the crossing

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* 1000 feet = 305 meters
340 feet = 103.7 meters
1500 feet = 457.5 meters
8 inches = 20.3 cm

SOUTHBOUND VIEW

NORTHBOUND VIEW

FIGURE 16
STANDARD AVENUE STROBE INSTALLATION

and approach section, including the traffic signal controlled intersection, to the south of the crossing. Marker lights provided fifty (50) foot* distance locations on the roadway approach to the crossing. The camera and intervelometer were manually started and stopped, prior to and following, train activations of the crossing signals. An observer was stationed to observe approach vehicle driver behavior and head movements (in particular).

Data collected over one daytime and nighttime period before strobe light activation contained 26 and 11 train activations, respectively. A similar test period two weeks following activation of the white strobe lights gathered data on 40 daytime and 14 nighttime train activations of the crossing signals.

5.1.5 Data Collection Results

Although the time lapse camera and roadway distance markers were intended to conduct vehicle deceleration analysis, it soon became clear that the upstream traffic signal, coupled with the previously mentioned driver behavior at this crossing precluded any meaningful deceleration analysis. This was either due to approach traffic being held up by the upstream traffic signal or when traffic was present at crossing signal onset, the lead approach vehicles presented an acceleration, rather than deceleration profile. Also, the overriding factors in speed, of the approach vehicles, were roadway congestion level and the pre-crossing activation status of the upstream traffic signal. The time lapse camera did, however, record driver behavior.

Based upon the comments of the observer and a review of the time lapse film, the safest behavior observed at the crossing in the daytime was either that of the public transit bus drivers who always stopped at the crossing and did not proceed until it was safe to do so, or the locomotive operators who were often observed to creep slowly onto and across the roadway, westbound from the Santa Fe's

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* 50 feet = 15.3 meters

switching yards. Although no train speed data was collected, these westward train movements out of the switching yards appeared to rarely exceed 10-15 mph.* Eastward train movement into the Santa Fe yards were consistently higher speed but, once again, rarely exceeded 15 mph*(estimate).

During the data collection periods, before and after, no observation was recorded of an emergency (panic) brake application. No observation was made, either before or after, where the lead vehicle drivers approaching the crossing appeared to be staring at the crossing signals. (It should be made clear that eye movements were impossible to see and only pronounced head movements were visible to the observer.) This lack of driver fixation on the strobes was also the case for stopped vehicles waiting for the train to clear the crossing, although only a few stopped vehicle drivers (front of the queue) were clearly visible to the observer.

There were only three observable head movements made by approach vehicle drivers looking at the train before running the flashing red lights in the daytime-before period. It should be pointed out that based upon a few sample counts of the number of flashing red light "running" (not stopping) vehicles it was only possible to sequentially observe head movements of 2-3 vehicle drivers from onset of activation until the train occupied the crossing.

Based upon several sample counts by the observer, the maximum number of vehicles who "ran" the crossing and could have stopped--was 16 on one occasion--on the south approach. The time lapse film recorded one activation where the number of flashing light "running" vehicles vastly exceed 16, however, sun glare into the camera lens precluded an accurate count which is estimated to be in the high twenties or low thirties (on the three lanes of the south approach). It should be made clear that the number of such vehicles exhibiting this behavior is strictly related to the traffic density at the time of crossing signal onset and the amount of time before the train reaches the roadway.

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*10 mph = 16 km/hr
15 mph = 24 km/hr

Only two pronounced head movements were observed on the southern approach (in the daytime after data collection period). These two head movements were made by drivers as they were running the signals. It should be pointed out that the daytime field of view approaching the crossing is excellent from the south. The foregoing, coupled with slow train approach speeds to the crossing, the train's location at signal onset, and the approach driver location 200-300 feet* back from the crossing, would make the train easily visible with only a slight movement of the driver's eyes.

The north approach to the crossing has an unrestricted view to the east, overlooking the Santa Fe switching yards. To the west, however, a building and parked vehicles block the approach vehicle driver's view until he reaches a location close to the crossing (approximately 100 feet* away). This restricted view results in a considerable number of head movements as the approach driver clears the building's sight restriction. These head movements, not tabulated in this direction, often occur even without the crossing being activated.

Based upon the conditions observed at this crossing, the researchers have concluded that head movement data (for this crossing) is far more related to sight distance limitations imposed within the crossing environs than to varying degrees of stimulation resulting from the attention-getting properties of the crossing warning system.

Nighttime driver behavior at the activated crossing is similar to the daytime behavior, though not as pronounced. Far lower vehicle traffic volumes result in fewer cases of vehicles running the flashing signals. There is more stopping, before proceeding, however, running of the flashing signals did occur, both before and after the strobes were installed. Before and after comparison of the frequency of such behavior is not presented as it might lead to a distorted view of the impact of the strobe lights. Also, such data is strictly based upon the opportunities to observe the behavior, which is in many cases a subjective deduction on the observers part, i.e., if an approach vehicle actually stopped, could he or could he not have run the flashing signals without having an accident.

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* 200 feet = 61 meters
300 feet = 91.5 meters
100 feet = 30.5 meters

FIGURE 17
NIGHTTIME EXPOSURE
STANDARD AVENUE CROSSING

5.1.6 Conclusions

Based upon review of the observer's comments, the time lapse film and discussions with people who either work in, live in or traverse this crossing daily, the following results can be reported:

1) There was no indication that the white strobes approach a level of brightness that would blind approach vehicle drivers, daytime or nightime, see Figure 17 for a nighttime (1-1/2 second film exposure) photo of the activated crossing.

2) Approach vehicle drivers showed no indication of staring at the strobe lights or being transfixed by their flashrate and pattern, even though their composite rate was eight (8) flashes per second.

3) Staring at these strobes and endeavoring to determine their pattern has thus far been limited, insofar as project feedback is concerned, to those people who went to look at the installation with that purpose in mind.

4) There is no basis to determine whether or not the white strobes had any positive impact upon (decreased) the number of vehicles that "run" the flashing signals, at nighttime particularly.

5) There were no vehicle/train accidents during the white strobe operational period of 1 April 1977 - 19 July 1977.

6) No panic type, driver braking maneuvers were observed during the "after" data collection period.

7) The only instance of direct driver reaction to the strobe light installation occurred when Santa Fe and project personnel were observing the head alignment on the

north approach (the strobes were flashing but the crossing flashers were inactive). A passing truck driver seeing the flashing strobes and people observing, honked his horn, pointed at the lights and gave a questioning shrug as he drove by. This was approximately 600 feet* to the north of the crossing with the strobes silhouetted against a bright afternoon sky, see Figure 16 - top picture.

5.2 Gate Arm Strobe Light Tests

The gate arm mounted strobe light tests featured the three, red, white and blue zenon capacitive discharge lamps as described in Section 9, Appendix D and proved to be the best among six gate/flashing light combinations. As stated, the gate mounting was red, white and blue, (in that order) while the gate positioning was red at the gate tip (where the steady burn incandescent is located), then white and blue positioned where the alternating gate mounted lights are normally placed; see Figure 9, Appendix D.

Each of the gate mounted strobe lights were designed to have individually selectable power in units 1, 2, 3, 4, 5, 6, 7, 8, and 9. The number of Joules corresponding to a unit power value is unimportant since the lights themselves were not designed to concentrate or focus the light energy in any particular direction, i.e., they consisted of a single, upright zenon tube, each surrounded by a red, blue and clear (white) plastic cylinder, see Figure 18. The small box located to the rear in Figure 18 is a continuously variable flash rate controller with the fixed flash pattern described in Section 9, Appendix D.

5.2.1 Field Site Location

The gate arm protected crossing site, was located on State Highway 58 near Boron, California. The roadway parallels the Santa Fe single track on either (opposite sides) approach to the crossing.

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* 600 feet = 183 meters

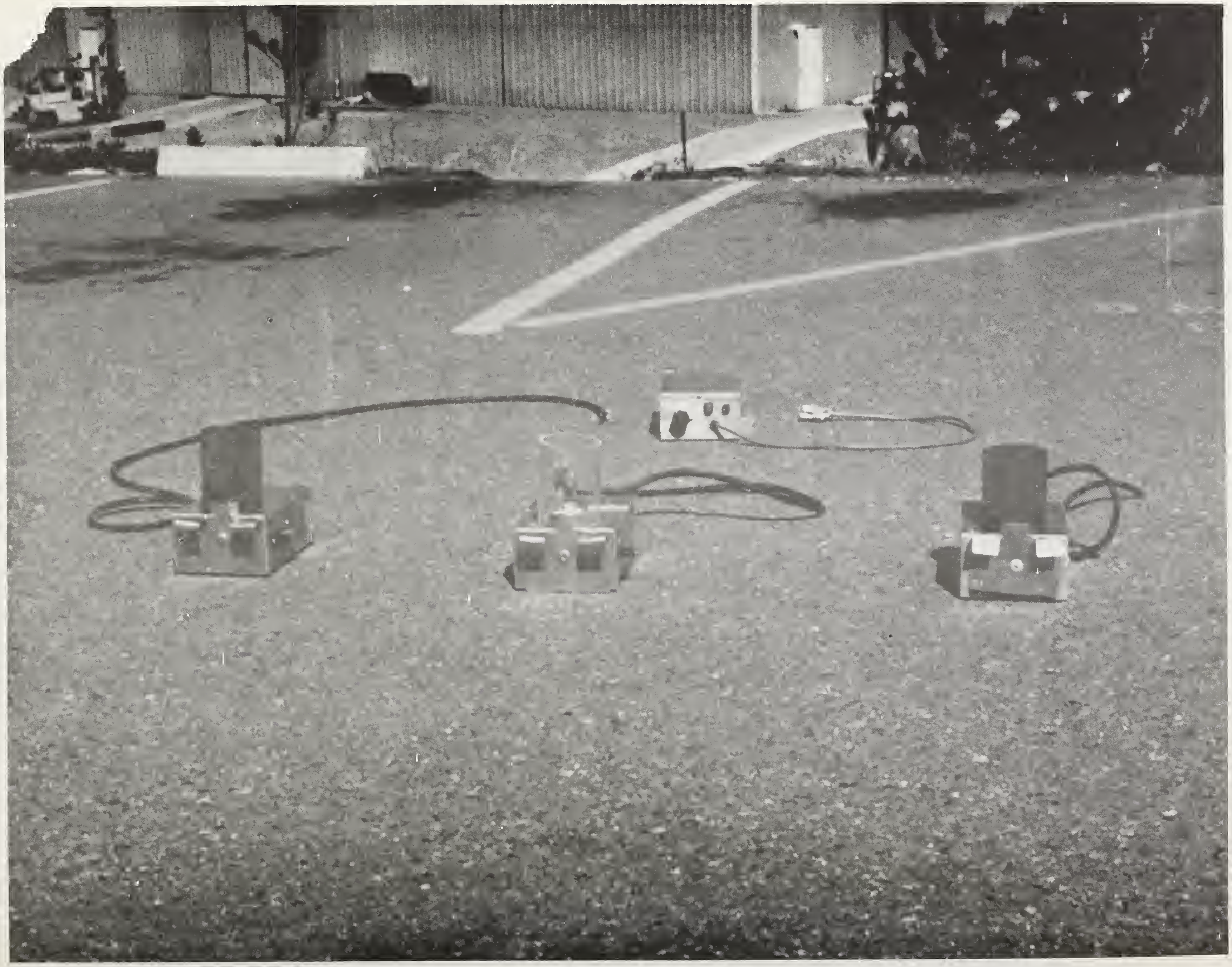

FIGURE 18
GATE ARM STROBES

Figures 19 through 24 and 25 through 30 present a view of the roadway at quoted distances from the Highway 58 crossing of the Santa Fe's single track line connecting Mojave and Barstow, California.

Train activity can range from 20/day at the very highest, to a very few (five). Daily vehicle traffic is 5600 (ADT). There has been no vehicle/train accidents since gates were installed, in 1973, following a fatality (vehicle train collision) at this location. The site, however, is plagued by a considerable amount of gate breakage, which is quoted to be both a day and night problem.

Two pairs of advance warning signs, one on either side of the roadway, inform the driver of the approaching vehicle of the upcoming crossing on both approaches. These five foot diameter signs are located at 300 feet[*] and 625 feet[*] from the crossing on the East side and 250 feet[*] and 700 feet[*] from the crossing on the West side. The highway curve signs are located 1250 feet[*] and 1400 feet[*] in advance of the crossing on the East and West roadway approaches, respectively.

The East side (Westbound roadway) of the crossing proved to be the ideal place for location of a tripod mounted doppler radar, with a pen recording device. The radar could measure and track vehicular deceleration characteristics as the driver approached the crossing. The tripod mounted radar was set low to the roadway between the two clumps of sage brush, located in front of the car appearing in Figure 23. The car, radar meter and recording tape were placed out of sight over the crest of the roadway, approximately 75 feet[*] from the radar head and tripod. Figure 31 shows the radar position view looking east. The radar was able to track most vehicles from 2200 feet[*], (Figure 19) to within 150[*] feet of its location, Figure 24, in the absence of other cars, oncoming or receding. Large trucks could be tracked for considerably longer distances. Since the radar position was located 350 feet[*] back from the crossing, looking east, the range of the radar speed coverage was the roadway zone between 2200 feet[*] and 500 feet[*] in advance of the crossing.

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[*] 1 foot = .3 meters

FIGURE 19
WESTBOUND: 2200 FEET*

FIGURE 20
WESTBOUND: 1600 FEET*

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* 2200 feet = 671 meters
1600 feet = 488 meters

FIGURE 21
WESTBOUND: 1200 FEET *

FIGURE 22
WESTBOUND: 800 FEET *

1200 feet = 366 meters
800 feet = 244 meters

FIGURE 23
WESTBOUND: 600 FEET *

FIGURE 24
WESTBOUND: 350 FEET *

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* 600 feet = 183 meters
350 feet = 106.8 meters

FIGURE 25
EASTBOUND: 2000 FEET *

FIGURE 26
EASTBOUND: 1600 FEET *

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* 2000 feet = 610 meters
1600 feet = 488 meters

FIGURE 27
EASTBOUND: 1200 FEET *

FIGURE 28
EASTBOUND: 800 FEET *

* 1200 feet = 366 meters
800 feet = 244 meters

FIGURE 29
EASTBOUND: 450 FEET*

FIGURE 30
EASTBOUND: 300 FEET *

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* 450 feet = 137.3 meters
300 feet = 91.5 meters

FIGURE 31
RADAR POSITION VIEW

The East approach to the crossing also provided the most interesting crossing apporach relative to the driver's eye height as he approached the crossing (large trucks possibly excluded), i. e., with the gate arms in the fully extended dropped position, the gate arm and lights were silhouetted against the sky.

Daytime observation of the existing incandescent lights, when flashing, revealed that they could not be seen beyond 200 feet * regardless of the gate arm position, up or down.

5.2.2 Strobe Light Power Settings

Considerable experimentation was conducted with the gate mounted strobes relative to their power settings (energy discharge per flash). With the white strobe on a power setting of unity (1) and the red strobe on a power setting of nine (9), the red strobe light was first to disappear as one backed away from the crossing. Further observation revealed that it required a blue strobe power setting of 3-4 times that of the white strobe so that both were of the same brightness when silhouetted against the bright sky. The nine (9) units of power coupled with the high flash rate exceeded the limits of the xenon tube rating and destroyed several tubes. Therefore, it was not possible to operate beyond eight (8) power units while testing.

The chosen daytime setting of strobe power was two units (white), four units (blue) and eight units (red); this rationale was based upon:

1) The energy discharge per flash would be decreased at night and there was only one remaining unit of power to which the white strobe could be lowered; and
2) To raise the power of the white or blue strobe would only serve to make the red strobe even more inconsequential in respect to its contribution to the test.

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* 200 feet = 61 meters

It may be concluded, therefore, from the above settings that the brightness, to the eye, of the three lights were white, blue and red in descending order. The relative brightness was not possible to discern at close range but was verified at longer distances, i.e., which disappeared first as one backed away from the crossing.

The nighttime power settings were 1, 2 and 6 units for the white, blue and red strobes respectively.

Observation of the white strobe settings revealed that a daytime power setting of six units did nothing to provoke any sensation of brightness discomfort. The white strobe was not observed at higher power settings in the daytime, nor more than one unit at night, since its observed brightness at these levels (one and two units) were already dominating the red and blue strobes.

Based upon field observations, it could be conjectured that two white strobes added to existing gate arm lights, would likely have provided far more attention-getting properties than the three gate mounted strobes tested in the field. This conjecture is supported by the results reported in Appendix D, section 9.

5.2.3 Data Collection

Since train activity is so light at Santa Fe's Boron located crossing, it would have taken considerable time to collect the necessary speed data to draw meaningful conclusions, if the field crew had to wait for train activations to take data. Secondly, based upon the experience gained at the Standard Avenue crossing, it was not clear that a train activated crossing signal would be concurrent with an approach vehicle being present, let alone in the position to establish a meaningful vehicle approach speed profile. It was therefore decided, with cooperation of Santa Fe personnel that data would be collected by manually triggering the crossing signal. Speed data was taken on 78 activations which were manually triggered over three daytime and two nighttime test periods. There were only three train activations over this period, when the field crew was prepared to take data. Two activations involved numerous vehicles at various locations on the radar covered approach and were impossible to analyze. One train activation provided usable data and occurred when the approach vehicle was roughly 2800 feet* upstream from the crossing. Fifty-two (52) of the 81 activations will be reported on as the other 29 consisted of some experimentation on the other approach leg or the loss of a complete record due to radar head misalignment, or the two previously mentioned train activations in which the data could not be analyzed.

The operational rules in manually triggering the crossing were:

1) To wait for vehicle gaps in both crossing approaches and entrap a Westbound vehicle, starting at 2200 feet* from the crossing and trace his velocity to within 500 feet* of the crossing

2) Deactivate the crossing when the approach vehicle reached 500 feet* (going into its roadway turn for the diagonal roadway crossing of the Santa Fe track).

3) Endeavor to minimize the number of vehicles to be effected (stopped) on the other approach.

It was soon learned that gaps of the magnitude satisfying the above three criteria are the exception rather than the rule. Rather than sacrifice any of the above three operational rules it was decided that uninterrupted radar speed profiles were not necessary. It was clear from observation that a continuous speed profile was not that important, so long as the 2200 foot* inbound speed and the 500 foot* inbound speed could be recorded. The radar is bi-directional and a receding vehicle from the radar position will interrupt an incoming track of an approach vehicle further away. The radar will, however, again pick up the approach vehicle as it passes (in the opposite direction) the receding vehicle upstream of the radar. Allowing a receding vehicle to interrupt the continuous incoming trackof the approach vehicle was

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* 2800 feet = 854 meters
2200 feet = 671 meters
500 feet = 152.5 meters

sufficient to provide the necessary traffic gaps and yet obtain two spot speed observations of incoming vehicles at 2200 feet* and 500 feet* upstream of the crossing.

5.2.4 Data Collection Results

Four vehicle speed decelerations are analyzed separately from the remaining 48 as they provide interesting comparison to the remainder of the data.

When testing initiated, the first procedure was to activate the crossing signals just as an approach vehicle passed the 2200 foot* mark. Due to excessive gate damage at the site the Santa Fe has a seven (7) second delay between flasher activation and onset of downward gate movement. It takes an additional eight (8) seconds for the gate to lower to the horizontal (down) position.

Observing the reactions of the first four vehicles (speed and driver behavior), it was clear that the oncoming drivers had spotted the downward gate movement. It is noted that an approach vehicle traveling <u>55 mph</u>* would traverse a roadway section during the gate movement of 645 feet.* The 645 foot* section would stretch from 1635 feet* to approximately 980 feet* from the crossing. This gate movement had a greater consistent impact on driver speed behavior than any lights that were daytime tested.

These four initial approach speeds at 2200 feet* ranged from 46-57 mph* and produced an average deceleration (as measured by the vehicles 500 foot* speed) of 23.5 mph,* the greatest average deceleration observed over any of four other data sets. These observations were taken in the daytime before the strobes were added to the gate arms, i.e., a "before" condition.

Following these four foregoing observations the policy of initiating the signal in advance of 2200 feet* was instituted. No other daytime "early decelerations" were observed to occur as a result of gate arm downward movements.

* 2200 feet = 671 meters
500 feet = 152.5 meters
55 mph = 88 km/hr
645 feet = 196.7 meters
1635 feet = 498.7 meters
980 feet = 298.9 meters
46 mph = 73.6 km/hr
57 mph = 91.2 km/hr
23.5 mph = 37.6 km/hr

It is impossible to assess the impact of downward movement of the gate arms in darkness as the crossing lights, pole mounted flashers and gate lights were clearly visible, both with and without strobes, from great distances.

The remaining four data sets are presented in the four categories:

1) Daytime: Before
2) Darkness: Before
3) Daytime: After (Strobes Installed)
4) Darkness: After (Strobes Installed)

Once again personal, on-the-spot observations indicated that six (6) approach vehicle drivers (daytime) had clearly noticed the gate mounted strobes in advance of the curve (500 feet)* and therfore the Daytime--After condition is separated into those "who saw" and those "who didn't see". The results are shown in Tables 1 and 2.

5.2.5 CB Radio Impact

The upstream observer (2200 feet* from the crossing), the radar operator and the person manually triggering the crossing signal (Santa Fe personnel) were linked by CB radio. Due to work load it was not possible to continuously listen to the local trucker's channel (17), although it was monitored intermittently. On several occasions the manual triggering of the gates did result in several CB Radio comments.

On one occasion, the field crew deemed it necessary to intervene, explain what was transpiring and seek truck driver cooperation in not continuing their conversation. The cooperation was nearly instantaneous. This occasion occurred when the driver of one of the trucks picked up the radar signal on his "fuzz buster," a radar jamming device which will operate both actively and passively. This event was beginning to produce considerable conversation. The amount of time spent in alerting one another regarding the location

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* 500 feet = 152.5 meters
2200 feet = 671 meters

TABLE 1
OBSERVED SPEED RANGES
GATE ARM STROBE TEST

CONDITIONS	Sample Size	OBSERVED SPEED & DECELERATION RANGES (MPH)			Average Deceleration *
		At Location 1 *	At Location 2 *	Deceleration *	
DAYTIME: BEFORE	10	51 - 59	50 - 58	0 - 4	1.1
DAYTIME: AFTER					
"Not Seen"	8	52 - 62	52 - 60	0 - 4	1.13
"Seen"	6	52 - 60	33 - 46	14 24	17.5
NIGHTTIME: BEFORE	12	46 - 63	26 - 43	9 - 24	17.4
NIGHTTIME: AFTER	12	50 - 62	28 - 50	4 - 24	15.8

* Location 1 : 2200 Ft. Upstream from Crossing

* Location 2: 500 Ft. Upstream from Crossing

* Deceleration: $S_1 - S_2$

S_1: Speed at Location 1

S_2: Speed at Location 2

1 mph = 1.6 km/hr
1 foot = .3 meters

TABLE 2
DECELERATION COMPUTATIONS
GATEARM STROBE TESTS

CONDITIONS	COMPUTATIONS						
	n	$\Sigma\Delta_i$	$\bar{\Delta}$	$n\bar{\Delta}^2$	$\Sigma\Delta_i^2$	$\Sigma(\Delta_i - \bar{\Delta})^2$	Sample Variance
DAYTIME: BEFORE	10	11	1.1	12.1	29	16.9	1.7
DAYTIME: AFTER							
"Not Seen"	8	9	1.13	9.0	29	20.0	2.5
"Seen"	6	105	17.5	1837.5	1917	79.5	13.3
Total ("Not Seen", "Seen")	14	114	8.14	928.3	1946	1017.7	78.3
DARKNESS: BEFORE	12	209	17.4	3640.1	3975	334.9	30.4
DARKNESS: AFTER	12	190	15.8	3008.3	3378	369.7	33.6

n: Sample Size

Δ: Deceleration of 6th Vehicle

$\bar{\Delta}$: Average Deceleration

1 mph = 1.6 km/hr

of "Smokey" coupled with what appeared to the truck drivers was a radar speed trap in a state (California) which prohibits the highway patrol from using radar for speed enforcement purposes, warranted intervention and explanation by the field test personnel before the radar location became the central conversation theme along State Highway 58.

What, if any, impact that CB radio transmissions had upon the vehicle speed behavior of drivers approaching the crossing is unknown.

5.2.6 Conclusions

There is no significance attached to comparison of the nighttime--before and after conditions. Comparison of daytime before data with all daytime (seen and not seen) after data (strobes installed) proves statistically significant at the .025 level. The category labeled Daytime: After-seen proves significant at the .001 level when compared with both the Daytime: After-Not Seen and the Daytime--Before data.

Subject to the data sample size, visual observations, test conditions and experiment plan:

1) Gate arm mounted strobe lights do not appear to add anything to the nighttime conspicuity of the existing gate mounted incandescent lights (at this test location).

2) Gate mounted strobes do add some increased conspicuity to the daytime crossing activations at this location as measured by significant observation of deceleration prior to the curve.

Gate arm breakage at this site has to be due primarily to the approach roadway geometry. Relative to the conditions observed, it is fairly clear that the porition of early deceleration attributed to the gate arm mounted strobes (daytime) could be better served by an activated advance warning device.

6.0 GUIDELINES FOR FUTURE EFFORTS

Based upon results of the study, it would have to be concluded that any research effort to increase the conspicuity of active gate crossing warning systems would utilize clear strobes (for maximum payoff) as add-on devices to the existing red railroad flashing pairs of lights. Using a red, blue or some other colored filter will only serve to severely attenuate the strobe intensity. Generally speaking, a red filter will drop the intensity by an order of magnitude (factor of ten). A blue filter will drop the intensity by a factor of 3-4.

The add-on 8-inch* white strobes should be pole mounted or cantilever mounted horizontally over a pair of red railroad flashing lights. The white strobes can number two or three and will fit on an existing cross arm (center plate modification necessary if three strobes are used).

Relative to the gate arm improvements, the 3-inch* diameter retro-reflector, red and clear, can be used effectively to increase the attention getting properties of the gate itself. In terms of lighting improvements to the gate, if needed, two small white strobes can be mounted between the existing three red incandescents on the gate arm.

Flash rate for an alternating pair of 8-inch* white (or colored) strobes is recommended to be 110 cycles per minute (or higher). Although not subject tested, flash rates were observed up to 150 cycles per minute without any "trance-like" condition being imposed upon an observer. Observation of a pair of alternating flashing strobes is a different phenomenon than observation of a single strobe flashing at the rate of 150 flashes per minute. This research does not recommend use of a single flashing strobe even though it may yield some improvement in conspicuity.

For a triple strobe, an outside alternating flash rate of 100-120 cycles per minute coupled with a center strobe, flash delayed 50 ms (milliseconds), following each outside strobe flash will produce an apparent movement among the lights.

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* 8 inches = 20.3 cm
3 inches = 7.6 cm

For a pair of gate mounted strobes, the type of flash patterns discussed in Section 9, Appendix D are recommended for future study. Three to four flashes per second (with varying time increment between consecutive flashes--but repeatable between groups of three or four) produces a random flashing pattern to the observer where the lights appear to "dance" on the gate arm.

None of the foregoing white strobes need to be of the blinding brilliant type, which all too many people erroneously associate with the word strobe itself.

A cylindrical 6-inch* to 12-inch* (length) shield around the 8-inch strobe lights will aid in directing the strobe light to oncoming vehicle traffic and limiting its off-the-roadway effects.

No strong reason is perceived which would warrant strobe light turn-off for the 8-inch* pole and cantilevered mountings when traffic is stopped waiting for the train to clear the crossing. The exception to the foregoing might well be the gate mounted pair of white strobes, which due to their position, directly in front of the driver's eyes, may warrant turn off when approach vehicle traffic is stopped at the crossing. A simple method to do the foregoing would be to use pavement embedded, vehicle occupancy detectors in each lane, at the stop bar. A four to six second delay timer on the occupancy signal would extinguish the strobes. If the occupancy signal disappears while the crossing is still activated, the strobes should then be flashed again.

Addition of white strobes will not overcome such site specific problems as obstructions to the driver's view or line of sight distance limitations based upon roadway approach geometry. Side of road pole-mounted installation may be sufficient to overcome competitive background and foreground competition. This improvement is certainly less expensive than cantilevered signals.

* 6 inches = 15.2 cm
12 inches = 30.5 cm
8 inches = 20.3 cm

APPENDIX A

1.0 ANNOTATED BIBLIOGRAPHY

This appendix contains the annotated bibliography prepared in the literature search portion of Phase I of the project. It is broken down into subsections by the following categorizations.

1) Conspicuity of Signals and Flashing Lights
2) Color of Lights
3) Restricted Visibility Studies
4) Accident Studies and Railroad-Highway Accident Predictors
5) Technical Inovations
6) Driver Behavior Approaching a Railroad Crossing
7) Sound Stimuli

References Concerning Conspicuity of Signals and Flashing Lights

1) Anonymous, Road Traffic Control Signals (General Considerations), Draft report by the Subcommittee on Signals, Technical Committee TC 1.6 (Fundamentals of Light Signals and Signs), International Commission on Illumination (CIE), July 1975.

2) Anonymous, Visual Detection of Air and Ground Targets, Report of Working Group 40, National Academy of Sciences - National Research Council Committee on Vision, 1974.

3) Anonymous, Conspicuity of Selected Signal Lights Against City-Light Backgrounds, Technical Report No. 13, Century Research Corp., June 1962.

4) Brown, B. and Cole, B. L., The Effect of Visual Noise on the Recognition of Road Traffic Signal Lights, Australian Road Research, Vol. 4, No. 1, 1969, 35-48.

5) Columbre, R. E., Rail Safety/Grade Crossing Warning Research Program, Proceedings, National Conference on Railroad-Highway Crossing Safety, U. S. Department of Transportation, August 1974, 77-84.

6) Cribbins, P. D. and Walton, C. M., Traffic Signals and Overhead Flashes at Rural Intersections: Their Effectiveness in Reducing Accidents, Highway Research Record, No. 325, 1970, 1-14.

7) Dahlstedt, S., The Reaction Time for the Change from Flashing to Steady Light in Traffic Signals, Swedish Road Safety Office, R&D Report No. 28, 1974.

8) Gerathewohl, S. J., Conspicuity of Flashing Light Signals of Different Frequency and Duration, Journal of Experimental Psychology, Vol. 48, No. 4, 1954, 247-251.

9) Gerathewohl, S. J., Conspicuity of Steady and Flashing Light Signals: Variation of Contrast, Journal of the Optical Society of America, Vol. 43, No. 7, 1953, 567-571.

10) Gerathewohl, S. J., Conspicuity of Flashing Light Signals: Effects of Variation Among Frequency, Duration, and Contrast of the Signals, Journal of the Optical Society of America, Vol. 47, No. 1, 1957, 27-29.

11) Hulbert, S. F. and Burg, A., A Human Factors Analysis of Barricades, Flashers and Steady Burn Lights for Use at Construction and Maintenance Work Sites, (Unpublished Report) December 26, 1974.

12) King, G. F., et al., Guidelines for Uniformity in Traffic Signal Design Configurations, Interim Draft Report to Transportation Research Board, KLD Associates, Report No. 38, May 1975.

13) Lindberg, V. L., How to Make Crossing Signals More Observable to Drivers, Railway System Controls, Vol. 2, No. 1, 1971, 24-30.

14) Markowitz, J., Optimal Flash Rate and Duty Cycle for Flashing Visual Indicators, Human Factors, Vol. 13, No. 5, 1971, 427-433.

15) McCain, T. A., The Influences of Attention and Perception on Successful Reception of Traffic Messages: A New Look at the Motorist, Napa, California, Casell Co., Inc., August 30, 1973.

16) Rumar, K., Conspicuity of Beacons for Emergency Vehicles, Uppsala University, Sweden, Report No. 152.

17) Wilburn, D., Halo Traffic Lights, Western ITE, Vol. 29, No. 7, August-September 1975, pp 1, 11.

Anonymous, Road Traffic Control Signals (General Considerations), Draft report by the Subcommittee on Signals, Technical Committee TC 1.6 (Fundamentals of Light Signals and Signs), International Commission on Illumination (CIE), July 1975.

Reviewer's Comments:

This is a draft of a report concerning the visibility aspects of traffic signals being prepared to serve as a background paper for international recommendations to be issued by CIE. It represents a compilation of research findings coupled with expert opinion. Covered are a wide range of topics, and a number of statements or recommendations are made that are relevant to the present study. These include the following:

1. For comparable detectability, a green signal must have an intensity 1.33 times that of red, and a yellow signal should be three times as intense the red.

2. Signals that have to function both at night and during the day should have at least two intensity levels. A maximum of 200 cd at night and at least 400 cd for daytime high speed roads are recommended.

3. Signals should be placed within a cone of 10° radius from the driver's normal line of sight.

4. Ground-mounted and overhead signals supplement each other--furthermore, in the event of sun glare, it will usually not affect both positions at the same time.

5. Backplates improve visibility by improving figure/ground contrast. The optimal background plate width is about three times the diameter of the signal.

6. It can be assumed that the optimum intensity of the signal is independent of its size, and therefore only the luminous intensity of the signal need be considered.

Anonymous, Visual Detection of Air and Ground Targets, Report of Working Group 40, National Academy of Sciences - National Research Council Committee on Vision, 1974.

Reviewer's Comments:

This report is concerned with an aviation problem--detection of air or ground targets--that has relatively little comparability to the rail/highway grade crossing problem. It is included in this bibliography, however, because it is based on a review of the literature and makes several statements of a general nature that are relevant. These statements have to do with target detection, and include the following:

1. All else being equal, luminance contrast is far more important to detection than color contrast, suggesting that in the present study, signal intensity is more significant than signal color.

2. Background luminance is a critical element in detection, as it influences target contrast. This reaffirms the importance of providing, as much as possible, an appropriate background (e.g., by means of backplates) for the crossing signals.

3. Loss of luminance--and, hence, contrast--due to intervening media (atmosphere, windshield) must be considered in establishing sight distance standards. This has significance for the manner in which detection data are collected in the present study.

Anonymous, Conspicuity of Selected Signal Lights Against City-Light Backgrounds, Arlington, Va.: Century Research Corporation, Technical Report No. 13, June 1962.

Published Abstract:

Detections of a small signal light against city-light backgrounds were made by experienced pilots during 288 presentations to determine whether detection time was affected by variations in signal characteristics and background, and whether pilot differences occurred.

The experiment yielded evidence that:

1. A red signal light was moderately more detectable than a green one, and the green moderately more so than a white light.
2. Some city backgrounds provided far more difficulty for detection of a flashing signal than others, the primary characteristics of difficult backgrounds apparently being high intensity, concentration of many lights, presence of one or more flashing lights, and wide variety of color.
3. Relative detectabilities among signal colors remained the same regardless of the predominant background color against which they were viewed.
4. A dot-dash flash pattern was significantly more detectable for some subjects and a series of dots more detectable for others.
5. Subjects did not differ significantly in detection time--in spite of using different search patterns.

Reviewer's Comments:

This study has strong implications for the influence of background visual stimuli on the conspicuity of the grade crossing signals. The atmosphere at the time of testing was clear, representing the most favorable condition. Allowance should be made for this fact.

Brown, B. and Cole, B. L., The Effect of Visual Noise on the Recognition of Road Traffic Signal Lights, Australian Road Research, Vol. 4, No. 1, 1969, 35-48.

Published Abstract:

Experiments concerning the effects of various configurations of background noise are reported. There appear to be two effects, one luminance-dependent which can be described in terms of an equivalent background luminance, and the other a "confusion" effect. The results are reported within the framework of a theoretical model for noise which might be useful for specifying complex backgrounds but which is not tested by the experiments reported.

If a signal has an intensity adequate for daylight use (i.e. 200 cd or more) then it is concluded that for the alerted observer the array of irrelevant lights of the kind commonly found as a background to signal lights in the urban environment at night is unlikely to have a significant effect on its conspicuity.

Reviewer's Comments:

This paper contains detailed descriptions of a number of research studies conducted in this area, and lists the following conclusions deriving from these studies:

1. Detectability of signal lights is enhanced by having black backgrounds and no competing stimuli.
2. A background of irrelevant lights constitutes "visual noise."
3. The background may disrupt pattern recognition (signal may be embedded), or background may contain dominant elements, more demanding than the signal.
4. If the background contains irrelevant steady lights, then the signal lights should be made flashing;

however, if the background contains flashing lights, then it is a disadvantage to have the signal flashing (unless it is made conspicously different from the other flashing lights).

5. Irrelevant lights cause disability glare in the same way as a uniformly bright background.
6. Signal detection will be degraded if the background lights increase in number and/or luminance.

The points discussed in this paper have obvious relevance to the grade crossing signalization problem, and suggest approaches as well as caveats in dealing with this problem.

Columbre, R. E., *Rail Safety/Grade Crossing Warning Research Program,* Proceedings, National Conference on Railroad-Highway *Crossing Safety,* U. S. Department of Transportation, August 1974, 77-84.

Reviewer's Comments:

In this paper, Columbre describes the U. S. DOT program at the Transportation Systems Center on Locomotive Conspicuity/Visibility Enhancement. In this study, xenon strobe lights were mounted on the top front left and right of locomotives, and compared with other devices (beacons, illuminated panels, etc.) from the standpoint of conspicuity. The strobe lights were found to be best from a subjective evaluation. Subsequent preliminary field evaluation results showed "motorist alerting and maintenance cost advantages attributable to the xenon strobe light.

These preliminary findings need verification from a controlled, large-scale study to be considered definitive.

Cribbins, P. D. and Walton, C. M., Traffic Signals and Overhead Flashes at Rural Intersections: Their Effectiveness in Reducing Accidents, Highway Research Record, No. 325, 1970, 1-14.

Published Abstract:

Two specific types of operational improvements - overhead flashers and traffic signals installed at low-volume, high-speed rural intersections--were selected for investigation. The effectiveness of the devices in reducing traffic accidents was earmarked as the primary objective of the analysis. Initially, all flashers and signal devices installed in North Carolina since 1965 were considered, but subsequent investigation and a more restrictive definition of a test site reduced the original inventory from 72 flashers and 153 signals to 14 flashers and 19 signals. A before and after study was made encompassing minimum time frames of 1 year prior to and immediately after installation of the device. Accident exposure during the two periods was compared on the basis of exposure rates, severity indexes, and equivalent property damage only accidents and rates. It was determined that the equivalent property damage only rate, rather than the normally used accident rate, was the most reliable and significant indicator of accident consequences. If all other factors were constant, any significant change in rate after installation of the control device could be attributed to the presence of the device. The relationship between the installation of signals and equivalent property damage only rate reduction was not statistically significant except for undivided highway intersections. The relationship between the installation of a flashing beacon and rate reduction was found to be statistically significant at the one percent confidence level.

Reviewer's Comments:

This study has general relevance to the present research by comparing steady burn and flashing lights as attention-getting devices. The flashers were shown to be superior.

Dahlstedt, S., The Reaction Time for the Change from Flashing to Steady Light in Traffic Signals, Swedish Road Safety Office, R&D Report No. 28, 1974.

Published Abstract:

The reaction time for the change from flashing to steady light in a traffic signal was studied in a laboratory situation. The results indicate that the shortest reaction times are obtained if the change is emphasized with an extra light, which is lit or extinguished at the same time as the signal changes from flashing to steady light. If an extra light is impossible or undesirable for any reason the shortest reaction time for a single light is obtained if its flashing frequency is as high as possible and the light portion of each light/dark cycle is as short as possible.

Reviewer's Comments:

The findings of this study have relevance for the choice of flash frequency and on/off ratio.

Gerathewohl, S. J., Conspicuity of Flashing Light Signals of Different Frequency and Duration, Journal of Experimental Psychology, Vol. 48, No. 4, 1954, 247-251.

Reviewer's Comments:

A laboratory experiment (similar to the author's 1953 study) was conducted utilizing approximately 230 subjects (S's). Flashing white signals of various frequencies and durations were presented to the subjects on a screen together with distracting visual stimuli. The luminance of the signals was varied to produce three contrast levels: high (74.2), medium (1.0) and low (0.19), where contrast is defined as target luminance minus background luminance divided by the background luminance. At each contrast, flash frequencies of 1, 2 and 4 flashes per second and flash durations of 1/2, 1/4 and 1/8 second were tested. The author summarizes his findings as follows:

> "The experiments reported here have produced evidence that when S is engaged in a very complex psychomotor task, and does not know when and where a light signal may appear, its efficacy as a warning or indicator is determined not by the luminance of a single flash alone, but by the conspicuity of a series of flashes. The results suggest that, if the brightness contrast is 1.00 or 74.20, i.e., according to our previous findings, close to or larger than 1.00, S will respond to a series of light flashes in a complex situation with about the same speed whether the flash becomes visible only once each second for 1/2 sec., two times for 1/4 sec., or whether it occurs four times per second for only 1/8 sec. At the low contrast, however, the fast flashing light of short duration seems to be more conspicuous than the slow flashing signal of a longer duration" (p. 251).

This study, then, has significance in terms of selecting the most appropriate frequency/duration combination for use in signal lights of a given contrast.

Gerathewohl, S. J., Conspicuity of Steady and Flashing Light Signals: Variation of Contrast, Journal of the Optical Society of America, Vol. 43, No. 7, 1953, 567-571.

Published Abstract:

In the past, two measures have been used to express the comparative effectiveness of steady and flashing light signals. These are comparative intensities (a) required for threshold; and (b) required for equal apparent brightness above threshold. The two measures agree in showing that the effectiveness of flashing signals is less than that of steady signal. The present study compares steady and flashing light signals with respect to conspicuity, defined as the speed of response to a signal above threshold. For large signal contrasts the conspicuity of steady and flashing signals is approximately equal. For small contrasts the conspicuity of flashing signals is considerably greater. These results suggest that flashing rather than steady signals be used for warning purposes.

Reviewer's Comments:

A laboratory study utilizing 241 observers was conducted comparing steady and flashing white spots of light projected on a screen 15° 30'' above the observer's line of sight. Bright spots of light appearing on the lower part of the screen were used to distract the observer. Auditory distraction also was used. Reaction time was the measurement variable.

The author studied nine contrasts between signals and background: 0.15, 0.33, 0.52, 0.74, 1.0, 6.6, 18.3, 139.0 and 1032.0. Signal brightness varied from 3.1 millilamberts to 2892.0 millilamberts, and background luminance from 2.2 to 2.8 ml. The observer had to move a lever when he became aware of a test signal, and had to move one of two other levers to respond to distractors.

The study revealed that:

1) For high contrasts (over 1.0), the conspicuity of steady and flashing lights was approximately equal.

2) For lesser contrasts (less than 1.0), the conspicuity of flashing lights was considerably greater.

Gerathewohl concludes by suggesting that flashing lights are superior to steady lights for warning purposes. This would seem to be especially true under low contrast situations such as are likely to be found during the daytime.

Gerathewohl, S. J., Conspicuity of Flashing Light Signals: Effects of Variation Among Frequency, Duration, and Contrast of the Signals, Journal of the Optical Society of America, Vol. 47, No. 1, 1957, 27-29.

Published Abstract:

This study deals with the conspicuity of flashing light signals of different frequencies, durations, and contrasts. It was planned to obtain information about the effects of these variables. The data show that at either high contrast or frequency, a change of the other factors does not produce a significant effect. At low contrast, however, conspicuity increases as flash frequency increases; and with low frequencies, conspicuity increases as brightness contrast increases.

Reviewer's Comments:

Eighteen observers viewed flashing white test signals on a screen while both visual and auditory distractors were also being presented (as in Gerathewohl's 1953 study). The interactions between frequency, duration and contrast were studied. Frequencies used were 1 flash per 3 seconds and 1, 2, 3 and 4 flashes per second; durations used were 1/10 sec., 1/8 sec., 1/5 sec., 1/4 sec. and 1/2 sec.; contrasts used were 0.16, 0.19, 0.95, 1.00, 11.16 and 74.20, with contrast defined as signal luminance minus background luminance divided by background luminance. The results were:

1) Response time decreases with increasing contrast, increasing flash frequency and increasing flash duration.

2) The above findings are more pronounced with low-contrast, low-frequency signals, but they are not too consistent.

3) At either high contrast or high frequency, a change of the other variable does not produce a large change in response time.

4) Gerathewohl reaches the tentative conclusion that under conditions tested thus far, the most conspicuous signal is one flashing three times per second when it is at least twice as bright as its background.

Hulbert, S. F. and Burg, A., A Human Factors Analysis of Barricades, Flashers and Steady Burn Lights for Use at Construction and Maintenance Work Sites (Unpublished report) December 26, 1974.

Reviewer's Comments:

This paper presents a general discussion of the human factors considerations in using signal lights in construction and work areas on the highway. Some of the principles discussed and conclusions reached are also applicable to the crossing safety problem. The most relevant conclusions are the following:

1. Moving or intermittent visual signals are several times more likely to be detected than non-moving or steady signals under the same viewing conditions.

2. Visibility standards must be established to take into account the likelihood of road users with poor vision (especially at night), less-than-fully-alert drivers, and less-than-optimum viewing conditions due to fog, dirt, rain, glare, etc.

3. Care must be taken to avoid an inadequate beam width for the warning signals to allow for possible misalignment and for highway geometry that may include vertical or horizontal curves.

King, G. F., et al., Guidelines for Uniformity in Traffic Signal Design Configurations, Interim Draft Report to the Transportation Research Board, KLD Associates, Report No. 38, May 1975.

Reviewer's Comments:

This report describes the results of a survey of 266 state, municipal and county traffic engineers with regard to current signal design practices and problems. Of more relevance to the present study is an analysis of 2,896 accidents at 532 signalized intersections as a function of signalization configuration. The authors also conducted speed studies on approaches to signalized intersections. Among the study findings are the following:

1. Post-mounted signals and cantilevered signals in combination were better than either one separately.
2. The use of larger lenses (12")[*] resulted in smoother traffic flow and fewer right-angle accidents.
3. The maximum visual angle for placement of traffic signals should be 10°, rather than the 20° specified in the MUTCD (Figure 4-2).
4. Multiple overhead signal configurations perform best in terms of operational effectiveness.
5. Brake applications occur further upstream than the minimum visibility distances specified in the MUTCD.

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[*] 12 inches = 30.5 cm

Lindberg, V. L., How to Make Crossing Signals More Observable to Drivers, Railway System Controls, Vol. 2, No. 1 1971, 24-30.

Published Abstract:

About one-third of all grade crossing accidents occur at crossings protected by flashing-light signals. The most common signal in use at crossings today is one in which the horizontal spread angle is 30° and the vertical deflection angle is 15°. The minimum brightness necessary for a flashing red signal to be detected in daylight has not been accurately determined but it seems that it probably lies between 100 and 400 candelas for a lamp the size of a crossing signal. Two new bulbs are described: the reflectorized bulb and the quartz-iodine bulb.

Reviewer's Comments:

This article has relevance because it suggests the range of luminances withing which effective crossing signal lights should fall.

Markowitz, J., Optimal Flash Rate and Duty Cycle for Flashing Visual Indicators, Human Factors, Vol. 13, No. 5, 1971, 427-433.

Published Abstract:

This experiment examined the ability of observers to determine, as quickly as possible, whether a visual indicator was steadily on or flashing. Six flash rates (periods) were combined factorially with three duty cycles (on-off ratios) to define 18 "types" of intermittent signals. Experimental sessions were divided into six runs of 100 trials, each run utilizing one of the six flash rates. On any given trial in a run, the probability of a steady signal occurring was 0.5 and the probability of a flashing signal occurring was 0.5. A different duty cycle was employed daily for each experimental session. In all, 400 trials were devoted to each of the flash rates at each duty cycle. Accuracy and latency of response were dependent variables of interest. The results show that the observers view the light for an interval of time appropriate to the expected flash rate and duty cycle; whether they judge the light to be steady or intermittent depends upon whether the light is extinguished during the predetermined waiting period. Adoption of this temporal criterion delays responding in comparison to those tasks involving responses to light onset. The decision or response criteria held by the observers are also sensitive to the parameters of the flashing light: observers become increasingly willing to call a flashing light "steady" as flash duration increases.

Reviewer's Comments:

The results of this study are of interest primarily because they suggest the importance of using short duration flashes to avoid confusion with steady signals.

McCain, T. A., The Influences of Attention and Perception on Successful Reception of Traffic Messages: A New Look at the Motorist. (Unpublished report) August 1973.

Reviewer's Comments:

This theoretical paper has relevance to the current study only in that it emphasizes the value of motion and redundancy as aids to perception. Current and proposed grade crossing warning systems all utilize motion (real or apparent) and redundancy (both intra- and inter-modality).

Rumar, Kare, Conspicuity of Beacons for Emergency Vehicles, Sweden: University of Uppsala, Department of Psychology, Report No. 152, 1974.

Published Abstract:

In a large field study, red, orange, light blue and dark blue rotating and flashing beacons have been studied mainly from peripheral conspicuity points of view. But also some subjective evaluation has been made.

The results show that from purely visual point of view the orange beacon is superior. The red beacon is inferior in nighttime conditions but good under bright daylight conditions which seem to be the worst from safety point of view. The blue beacons are almost too good in nighttime conditions in the respect that they cause discomfort but they are poorly visible in bright daylight conditions. A light blue beacon improves visibility in daylight. Flashing light blue beacons are equally conspicuous to rotating light blue beacons but cause more discomfort.

The positive (attention, warning and directional value) and negative (glare and discomfort) aspects of a beacon are dependent mainly on:

1. The physical characteristics of the light source (energy amplitude and frequency, wavelength, time sequence, area).
2. The background characteristics which form the important contrast (luminance, wavelength, change, complexity).
3. The atmospheric characteristics (clear, fog, dust, snow, rain, etc.).
4. Visual characteristics (adaptation level, position on the retina, color vision, age).

5. Psychological characteristics (arousal, fatigue, motivation, experience, expectation, etc.).

Reviewer's Comments:

A total of four separate field experiments were carried out, using from four to ten subjects in each one, to evaluate peripheral conspicuity of flashing or rotating beacons of different colors. The beacon stimulus was presented by means of a movable mirror at positions ranging from 10° to 98° off the subject's line of sight. Tests were run in daylight, twilight and in darkness, with and without own car headlighting, in daylight with snowfall, and in darkness with and without distracting light sources. In addition, subjects centrally viewed the various beacons and gave subjective evaluations of intensity, warning effect, color and discomfort glare.

The basic beacon type used was equipped with a 55 watt halogen H_1 bulb surrounded by a rotating metal reflector and a plastic color filter which was changeable to provide the four colors tested: dark blue, light blue, orange and red. Another beacon was used that had the same bulb but surrounded with three rotating glass lenses. Both of these beacons had a beam width of 10° horizontally and 20° vertically. The rotating frequencies used were approximately 170 per minute initially, and approximately 125-130 per minute subsequently.

The flashing beacon used had a xenon gaseous discharge lamp (Whelen Strobe 1200) surrounded by a prismatic spreading lens giving a 360° horizontal and 20° vertical beam. The on-time was .05 second for the rotating beacons and .0005 seconds for the strobe. Flash frequency was 125-30/minute. The peak intensity of the strobe was about 100 times that of the rotating beacons.

The Rumar study is the most comprehensive one to date in the area of conspicuity of flashing lights, and its findings have many applications to the grade crossing problem.

Wilburn, D., Halo Traffic Lights, Western ITE, Vol. 29, No. 7, 1975, 1, 11.

Reviewer's Comments:

This article describes a field study in Eugene, Oregon, in which a "Halo Traffic Light" was installed at a high-accident intersection in the city. The device consists of a standard 8-inch* red traffic signal lens surrounded by a white ring strobe light flashing at a frequency of 50 per minute. The strobe is activated only when the red signal is on, and is surrounded by a visor to direct its light in the desired direction. Records kept over an eight-month period showed no "running the red light" accidents at this intersection, compared with four such accidents during the same time period the previous year. Public reaction was favorable. A followup study using 12-inch* lenses, and a third study again using the halo lights were planned.

One of the drawbacks to the device seemed to be its propensity for being confused as a flashing red light. However, the concept appears worthy of consideration for use in the grade crossing situation.

* 8 inches = 20.3 cm
12 inches = 30.5 cm

References Concerning the Color of Lights

1) Pudinski, W., Blue Lights - California Reports, Police Chief, Vol. 15, No. 11, 1973.

2) Paulson, S. L., Blue Lights - Status of and Present Use, Police Chief, Vol. 15, No. 11, 1973

3) Nathan, R. A., What's the Safest Color for a Motor Vehicle? Traffic Safety, Vol. 69, No. 9, 1969, p. 13 and p. 42.

Pudinski, W., Blue Lights - California Reports, Police Chief, Vol. 15, No. 11, 1973

Published Abstracts:

The California Highway Patrol recently conducted a study to determine what color and type of light for patrol cars are the most visible under various lighting conditions, and to determine which light would have the most significant effect on traffic, since the basic task of the light is to alert drivers to potential problems. The typical red light has been critized because approximately two thirds of the population perceives red objects as being farther away than they actually are, a portion of the public is red-green color blind, and at low levels of illumination, reaction is slower to a red light. Blue, red, and amber lights were tested in sealed, revolving, and strobe types. They were tried in various combinations, on varied road settings, under night and day conditions, and from all angles. The combination of blue and red strobe lights provided the positive effects of both red and blue and proved to have the maximum efficiency of any tested.

Reviewer's Comments:

This article summarizes the results of a field evaluation of blue, red and amber lights for law enforcement vehicles. The findings need validation before they can be applied to any other situation calling for motorist warning.

Paulson, S. L., Blue Lights - Status of and Present Use, Police Chief, Vol. 15, No. 11, 1973.

Published Abstracts:

The question of red or blue lights for police car use is a controversial one. A California Highway Patrol study recommended both a red light and a blue one on patrol cars with overhead light bars. Following a similar study, the Maryland State Police have installed bars of two red and two blue lights on their patrol cars. Connecticut attributes a 20 percent decrease in accidents to the use of blue lights. Yet Michigan rejected the use of blue lights on the basis of a study that showed blue and white lights at the intensity used on patrol cars would bleach the retina of the eye causing a loss of visual night sensitivity. The arguments in favor of blue are: the eye is more sensitive to the blue wavelengths in peripheral vision, blue would promote international uniformity, because of the widespread use of red lights for other than police business, blue would be a distinctive warning light. The arguments against blue are: blue is not widely recognized as conveying emergency or warning, it is necessary to use more power for blue lights, and that nationwide standardization to blue would cost more.

Reviewer's Comments:

This article does not represent an experimental study, but does summarize some of the arguments in favor of and against using blue lights in law enforcement. The validity of some of these arguments has yet to be determined.

Nathan, R. A., What's the Safest Color for a Motor Vehicle? Traffic Safety, Vol. 69, No. 9, 1969, 13, 42.

Published Abstract:

There seems to be no unanimous opinion on the safest color for motor vehicles. In studies conducted at the University of California, it was shown that the color of an approaching auto influences a driver's judgment of how far away the vehicle is. Of the various colors tested on 164 subjects, blue and yellow made distant objects seem closest--under both daytime and nighttime conditions. Grey shades made objects appear farthest away. White vehicles have low visibility in snow storms and on light-colored pavement in bright sunlight. A Swedish color expert stated that black was probably the most dangerous color, the safest color being pink. As evidences by post office department tests, color combinations can increase a vehicle's visibility. The character of reflection is also important. A dull surface giving a diffused reflection is more desirable than a glossy surface which may reflect glare into the eyes of an approaching driver. A table is given listing approximate light reflection percentages of a number of standard colors.

Reviewer's Comments:

If it is possible to generalize from surface colors to signal lights, then it would appear that the use of blue or yellow signal lights at crossings would introduce an additional safety factor, by causing motorists to react sooner to the presence of the crossing.

References Concerning Restricted Visibility Studies

1) Anonymous, Report on Reduced Visibility (Fog) Study, Sacramento: California Division of Highways, February 1967.

2) Blackwell, H. R., Roadway Illumination and Visibility in Fog, Journal of the Illuminating Engineering Society, Vol. 1, No. 1, 1971, 45-59.

3) Cole, B. L., Visual Aspects of Road Engineering, Proceedings, Australian Road Research Board, Vol. 6, Part 1, 1972, 102-148.

4) Dunn, A. R., The Effect of Light Absorbing Media on Driver Visual Performance, Huntsville, Alabama: Teledyne Brown Engineering Co. Report No. SE-DOT-1685, January 1973.

5) Hills, B. L., Measurements of the Night-time Visibility of Signs and Delineators on an Australian Rural Road, Australian Road Researcher, Vol. 4, No. 10, 1972, 38-57.

6) Kocmond, W. C. and Perchonok, K., Highway Fog, Highway Research Board, National Cooperative Highway Research Program Report No. 95, 1970.

7) Lane, F. D. and Pfau, J. L., Speed Advisory Information for Reduced Visibility Conditions, Salem: Oregon State Department of Transportation, Report No. FHWA-RD-75-66, May 1975.

8) Projector, T. H., Porter, L. G. and Cook, K. G., Effects of Backscattered Light on Target Light Detectability in a Ground Test Environment, Technical Reports Nos. 6, 9 & 14, Century Research Corporation, July 1962.

Anonymous, Report on Reduced Visibility (Fog) Study, Sacramento: California Division of Highways, February 1967.

Reviewer's Comments:

This report covers a survey of driver speed as a function of fog density and posted speed. It was found that the presence of fog caused a speed reduction of 5-10 mph,* depending on the density. Also, both regulatory and advisory posted speed limits had a nominal additional effect in reducing speeds 5-10 mph* and occasionally in reducing the speed variance of the traffic stream. However, these reductions were found only for low volumes, and the survey was conducted only on freeways and expressways.

The important finding of this survey is that "even with the combined effect of fog and posted speed signs, the resultant speeds were still greatly in excess of those considered safe for the reduced visibilities existing," (p. 22). This emphasizes the need to provide warning signals of sufficient conspicuity to be effective at producing safe stopping distances in at least moderate fog conditions.

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* 5 mph = 8 km/hr
10 mph = 16 km/hr

Blackwell, H. R., Roadway Illumination and Visibility in Fog, Journal of the Illuminating Engineering Society, Vol. 1, No. 1, 1971, 45-59.

Reviewer's Comments:

A series of laboratory studies using model vehicles in a simulated highway environment were conducted. Artificial fog was generated, and visibility of lead vehicles was studied when illumination was provided either by the following vehicle's headlights or by fixed roadway lighting of different kinds. The results showed:

1. Using fixed spotlights, the most favorable orientation was to point them ahead by 60°.
2. Visibility changes much more rapidly with distance in fog then is the case in the absence of fog. Thus, objects seem to suddenly "break out" of the fog, and rapidly become quite visible.
3. Either high or low roadway-mounted spotlights provide significant improvements in visibility distances over vehicular headlights under most conditions. High-mounted spotlights are better than low-mounted for lesser fog densities, while the reverse is true for greater fog densities.
4. Vehicle taillights are more visible than a dark auto body at all fog densities. However, a light auto body is more visible than taillights for optical ranges of 100 feet* or more. When the following vehicle's headlights are on, the lead vehicle's taillights are always much more visible than even the light auto body.
5. Blackwell concludes that fixed roadway spotlighting leads to significant improvements in visibility especially in the absence of vehicular taillights.

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* 100 feet = 30.5 meters

6. When the level of horizontal illumination provided by the fixed roadway spotlights falls below about 0.1 fc, headlights increase visibility. However, above that level, up to about 20 fc from the spotlights, headlights reduce visibility. Above 20 fc, headlights have no effect. The reduction of visibility due to headlights when the fixed illumination is between 0.1 fc and 20 fc is due to veiling luminance.

7. There is always a tendency for stratification of fog in layers parallel to the road surface, with lesser fog density near the road.

The study findings have implications for the crossing safety problem with regard to placement of signals as a function of the site (amount of fixed illumination present, prevalence of fog) and with regard to the degree of dependence to be placed on vehicle headlights in illuminating the hazard.

Cole, B. L., Visual Aspects of Road Engineering, Proceedings, Australian Road Research Board, Vol. 6, Part 1, 1972, 102-148.

Published Abstract:

Vision is the principal sensory channel for acquisition of information upon which the driver makes his decisions concerning the guidance of his vehicle. It is therefore necessary for road and traffic engineers to have a knowledge of the visual capabilities of the driver population if roads, road furniture, lighting systems and vehicles are to be designed so that adequate visual information is conveyed to the driver reliably and rapidly.

The driver's visual task can be considered to comprise the following attributes:

(a) detection (of obstacles, delineation and signal lights)
(b) temporal resolution (of flashing and flicking lights)
(c) spatial resolution (of road sign legends and symbols)
(d) colour discrimination (of colour coded signs and signals), and
(e) spatial relationships (the perception of direction, depth and movement).

This paper reviews the capabilities of the human visual system for each of these attributes except the last.

About one in every five drivers will have a visual capacity for one or more of these attributes except the last.

About one in every five drivers will have a visual capacity for one or more of these attributes which falls short of the maximum attainable.

It is argued that the visual requirements imposed by licensing authorities do not (and should not) exclude these drivers from holding a license to drive; rather, road design should account for defective vision. The paper reviews the common defects of vision and considers their effect on design.

Reviewer's Comments:

This excellent report represents an extensive and detailed summary of research conducted to 1972 relating visual capabilities to the demands of the driving task. A broad variety of topics is covered, including a thorough discussion of detection of signal lights. A brief summary of this lengthy paper is not possible; however, some of the more relevant points brought out include the following:

1. Irrelevant background lights degrade detection performance for a signal. However, Cole feels that "It is possible that visual noise may be a factor in driving only when the driver does not expect an event or is uncertain of the location of the event." (p. 116).
2. Cole presents a nomogram for red signal light intensity needed for high detection probability as a function of distance and background luminance.
3. Flashing lights are more conspicuous than steady ones because they "occur rarely in nature and the visual system is not well prepared for flash stimulation" (p. 120). However, "It appears that a steady signal is just as conspicuous as a flashing one for intensities in excess of the optimum signal intensity" (p. 120).
4. Color contrast can be used as a partial substitute for luminance contrast.
5. Color discrimination can be unreliable with small light stimuli (e.g., blue and green are confused, as are yellow and white).
6. Steady burn lights are advisable for delineation.

Dunn, A. R., The Effect of Light Absorbing Media on Driver Visual Performance, Huntsville, Alabama: Teledyne Brown Engineering Co. Report No. SE-DOT-1685, January 1973.

Published Abstract:

Analytical and experimental determinations were made of the effects of windshields and filters on probability of detecting objects and on seeing distances after dark. The analytical study showed that visual degradation increases more rapidly for filter transmittances less than 79 percent. The experimental study showed that seeing distances through clear windshields are greater than those through tinted windshields; the difference is less than 15 feet[*]. The seeing distances attained by individual observers ranged from 200 to 600 feet.[*]

The possibilities of eye damage from looking at the sun through automobile glasses were studied. Damage can be sustained through all types of glass studied. In particular, the shaded bands at the tops of windshields may increase the probability that a driver will sustain a retinal burn. Recommendations for automobile glass transmittances were made from the results of the analyses.

Reviewer's Comments:

This study collected laboratory data for 35 subjects on the filter properties of clear and tinted windshields, sun visors, sun glasses and several other types of opthalmic lenses, utilizing neutral gray targets as well as standard red, yellow and green traffic signal lights. A second part of the study collected field data on seeing distance after dark, again using 35 subjects. High beam headlamps were used for illumination, and a neutral gray target (9.3 percent reflectance) was viewed through both clear and tinted windshields.

The significance of this research for the present study is that it verifies the fact that calculated seeing distances for various types of stimuli must be corrected for several types of media commonly in use. Design standards for placement of warning signs and signals must therefore take this reduction in light transmittance in account.

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[*] 15 feet = 4.6 meters
200 feet = 61 meters
600 feet = 183 meters

Hills, B. L., Measurements of the Night-time Visibility of Signs and Delineators on an Australian Rural Road, Australian Road Researcher, Vol. 4, No. 10, 1972, 38-57.

Published Abstract:

The visibilities of in-service signs and delineators have been measured under practical driving conditions on a four-lane divided highway. The night-time experiments were conducted using American-British dipped beams. It was found that the nighttime legibility distances of reflective signs were on an average half those obtained during the daytime. Aging and dirt accumulation were shown to reduce sign legibility distances by 30 percent or more at night. These same factors were found to reduce the reflectivity of delineators on guide posts set back 10 feet* from the pavement by as much as 18 times. The corresponding reduction in visibility was from 1,000 feet* to less than 100 feet.* The mean detection distance for the three feet* guide posts was 590 feet* for normal observers. On average, the guide posts were found to be slightly more visible than their red delineators. For a color defective (protanomal) observer, the mean detection distance of the delineators was half that of the guide post. Heavy rain was found to have little effect on the performance of enclosed lens reflective sheeting, although other evidence suggests that drizzle can reduce its visibility considerably.

The dependence of current signing and delineation practices in Australia upon a high level of maintenance has therefore been shown. The study also indicates that there is a need for a careful examination of the present standards for delineators.

Reviewer's Comments:

This article is included to emphasize the fact that design standards for safe stopping distance should not be based on the assumption of a "new" condition for the crossing signal system (including the reflectorized gate arms).

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* 1000 feet = 305 meters
100 feet = 30.5 meters
590 feet = 180 meters
10 feet = 3.1 meters
3 feet = 0.9 meters

Kocmond, W. C. and Perchonok, K., Highway Fog, Highway Research Board, National Cooperative Highway Research Program Report No. 95, 1970.

Published Abstract:

A review of the literature shows that fog has had the following effects: (1) a slight reduction in accident frequency, (2) an increase in the likelihood that an accident will result in a fatality, and (3) an increase in the likelihood that accidents will involve either a single vehicle or more than three vehicles.

Traffic measurements made during this project indicate that: (1) speeds were slightly lower in fog, (2) the probability of overdriving one's visual range was greatly increased, and (3) lateral location and vehicle interactions were not affected by fog. It is concluded that drivers exercise more caution in fog, but that the increase in overdriving probably explains the increased severity of accidents.

Field tests have demonstrated that visibility in dense fog can be improved by seeding with practical amounts of carefully sized hydroscopic material. Additional studies are needed to refine seeding procedures and to determine the scope of application for highway fog abatement. Other concepts (e.g., vegetation barriers to influence the movement of shallow fog, monolayers to inhibit evaporation from water reservoirs, use of helicopters to mix drier air with fog) have limited application and may be tailored to specific types of highway fog. These concepts are discussed in this report.

Previously suggested vehicle guidance procedures were studied. It was determined that specially designed lights mounted near the road surface, producing an area of illumination directed about 110° to the direction of traffic flow can be used to effectively provide illumination for night driving in fog.

A vehicle guidance system involving the use of polarized headlamps was evaluated in field experiments and judged impractical as an aid to drivers in fog.

Measurements of the effect of vehicle lighting on visibility showed that rear lighting systems can be improved to allow better detection of vehicles in fog.

Reviewer's Comments:

This report contains a literature review and also describes a study of the effects of fog on driver behavior. The findings of the literature review are that speeds in daylight fog tend to decrease by approximately 4.5 mph* as visibility decreases from over 1000 feet* to approximately 250 feet* and that the probability of overdriving in fog increases sharply as visual distance decreases (this probability is higher for isolated vehicles). This suggests the importance of designing adequate visibility (detection distance) into signaling systems.

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* 4.5 mph = 7.2 km/hr
1000 feet = 305 meters
250 feet = 76.3 meters

Lane, F. D. and Pfau, J. L., Speed Advisory Information for Reduced Visibility Conditions, Salem: Oregon State Department of Transportation, Report No. FHWA-RD-75-66, May 1975.

Published Abstract:

This project is being conducted to develop preliminary design specifications for a speed advisory system for use during periods of reduced visibility (fog). Phase I of the program consisted of developing the necessary facilities, equipment and procedures to conduct controlled experimentation under various levels of fog density. Phase II consists of a series of interrelated experiments to identify optimum advisory information (sign messages and speed values), and the number, locations and interconnections between signs which will result in the smoothest traffic flow. Phase III will utilize this information, as well as the pertinent literature, to develop detailed specifications for a full-scale advisory system for testing on a public highway.

This report covers the activities of Phase I and the preliminary results of the first two experiments of Phase II. The facilities, equipment and procedures developed are described as well as some of the problems encountered in their development.

The first study of Phase II was concerned with determining what speeds drivers normally drive at under various conditions of reduced visibility. Fifty-one subjects made a total of 144 fog runs at 100, 200, 300 and 400 foot* visibilities. The drivers speed distributions were obtained and the 15th, 50th, and 85th percentile speeds calculated for each condition. The second study was intended to determine which of the percentile speeds from Study I would result in the smoothest traffic flow when used as a posted speed for each of the four visibilities. One hundred five subjects made a total of 140 runs under the 12 speed-visibility conditions. Although only a first level analysis has been completed, the results indicate that the posted speed sign had little or no effect (regardless of which percentile speed was posted) upon driver performance in terms of mean speed through the fog. Additionally, the

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* 100 feet = 30.5 meters
200 feet = 61 meters
300 feet = 91.5 meters
400 feet = 122 meters

presence of the posted speed was found to have a slightly detrimental effect upon traffic stability. This was evidenced by an increase in speed variance for the conditions of Study II when a posted speed was present over similar visibility conditions of Study I when the sign was not present. For Study II, little in the way of a systematic effect was found for the posted speeds within visibility conditions. A more detailed analysis of the data is suggested and is being conducted. The report also contains a description of the remaining studies in Phase II.

Reviewer's Comments:

This study of driver speed selection as a function of visibility was conducted with volunteer drivers at a specially selected field location. The findings are similar to those of other research studies involving unsuspecting drivers. The average maximum drop in speed was approximately 22 mph* for 400-foot* visibility, 27 mph* for 300-foot* visibility, 33 mph* for 200-foot* visibility and 39 mph* for 100-foot* visibility. However, speeds upon entering the fog zones were consistently too high to allow adequate perception-reaction-stopping time, reinforcing the need for adequate signal conspicuity under such conditions.

* 22 mph = 35.2 km/hr
400 feet = 122 meters
27 mph = 43.2 km/hr
300 feet = 91.5 meters
33 mph = 52.8 km/hr
200 feet = 61 meters
39 mph = 62.4 km/hr
100 feet = 30.5 meters

Projector, T. H., Porter, L. G. and Cook, K. G., Effects of Backscattered Light on Target Light Detectability in a Ground Test Environment, Arlington, Va.: Century Research Corporation, Technical Reports Nos. 6, 9 and 14 (combined), July 1962.

Published Abstract:

Field tests were conducted to determine how ability to detect target lights is affected by backscattered light (light reflected back to the pilot from his own exterior lights), under VFR atmospheric conditions.

Backscatter was generated by a light with a peak intensity of 5500 candles. It was varied in color (red, green, white), lateral displacement (0 and 15 feet),* flashing mode (flashing or steady burning), and beam alignment with the target. Target light colors were also varied (red, green, white). Subject viewed the target both foveally and peripherally. Atmospheric transmissivity was measured during the tests.

Results indicate that backscatter has little effect on detectability of target lights in atmospheric transmissivities of about 20 percent per mile* and greater. Differences in threshold could, in the main, be accounted for by atmospheric transmissivity and differential sensitivities of the eye. The striking differences in the subjective appearance of different backscatter colors and modes of flashing suggest that other effects such as distraction, fatigue, and disorientation may not be negligible, even though target detectability is not affected.

Reviewer's Comments:

The relevance of this study to the crossing problem has to do with the reduction in detectability of signal lights to be expected in a fog situation at night, a consideration in establishing design standards.

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* 15 feet = 4.6 meters
1 mile = 1.6 km

References Concerning Accident Studies and Railroad-Highway Accident Predictors

1) Berg, W. D., Schultz, T. G. and Oppenlander, J. C., Proposed Warrants for Protective Devices at Railroad-Highway Grade Crossings, Traffic Engineering, Vol. 40, No. 9, 1970, 36-38, 40-42.

2) Berg, W. D., Schultz, T. G. and Oppenlander, J. C., Proposed Warrants for Protective Devices at Railroad-Highway Grade Crossings: Part I - Rural Areas, Traffic Engineering, Vol. 40, No. 8, 1970, 38, 42-43.

3) Butcher, T. A., Evaluation of Safety Improvements at Highway - Railway Grade Crossings, Purdue University, Indiana State Highway Commission, Interim Report JHRP-1-73, Joint Highway Research Project C-36-59N, February 1973.

4) Carmody, D. J., Lighted Crossings Are Safe, Rural and Urban Roads, Vol. 4, No. 9, September 1966, 90-91.

5) Mitchell, R., Identifying and Improving High Accident Locations, Public Works, Vol. 103, No. 12, December 1972, pp 75-76.

6) Russell, Eugene R., Analysis of Driver Reaction to Warning Devices at a High-Accident Rural Grade Crossing, Purdue University, Indiana State Highway Commission, Joint Highway Research Project 74-16, 1974.

7) Schoppert, D. W. and Hoyt, D. W., Factors Influencing Safety at Highway-Rail Grade Crossings, Highway Research Board, National Cooperative Highway Research Program, Report No. 50, 1968.

8) Schultz, T. G., Berg, W. D. and Oppenlander, J. C., Evaluation of Rail-Highway Grade Crossing Protection in Rural Areas, Highway Research Record, No. 272, 1969, 14-23.

9) Schultz, T. G., Evaluation of Safety at Railroad-Highway Grade Crossings, Purdue University and Indiana State Highway Commission, Joint Highway Research Project, Report No. 9, September 1965.

Berg, W. D., Schultz, T. G., and Oppenlander, J. C., Proposed Warrants for Protective Devices at Railroad-Highway Grade Crossings, Traffic Engineering, Vol. 40, No. 9, 1970, 36-38, 40-42.

Published Abstract:

This paper develops procedures to evaluate accident potential and to specify minimum protective devices for urban grade crossings. Four variables--relative exposure to potential collisions, roadside distractions, type of protective device, line of sight ratio--are based on readily obtainable field data. A graph is provided to aid judgment in selecting a maximum tolerable accident prone probability (probability of underprotection). With the use of the nomograph and design charts the potential hazard and minimum protective device may be determined for each crossing. A rank ordering of potential hazards provides priority ratings for scheduling improvements. An example is provided, using five grade crossings in a typical community.

Berg, W. D., Schultz, T. G. and Oppenlander, J. C., Proposed Warrants for Protective Devices at Railroad-Highway Grade Crossings: Part I - Rural Areas, Traffic Engineering, Vol. 40, No. 8, 1970, 38, 42-43.

Published Abstract:

This paper develops procedures to evaluate accident potential and to specify minimum protective devices for rural grade crossings. Five variables--relative exposure to potential collisions, driver distraction, type of protective device, pavement width, and number of tracks--are based on readily obtainable field data. With the use of the nomograph and design charts the potential hazard and minimum protective device may be determined for each crossing. A rank ordering of potential hazards provides priority ratings for scheduling improvements. An example is provided, using five rural grade crossings.

Butcher, T. A., Evaluation of Safety Improvements at Highway - Railway Grade Crossings, Purdue University, Indiana State Highway Commission, Interim Report JHRP-1-73, Joint Highway Research Project C-36-59N, February 1973.

Published Abstract:

In recognition that added effort must be placed on reducing the conflict at highway-railroad grade crossings, this research to evaluate means of supplying motorists with more credible and forceful information was developed. Many innovative active protection devices for grade crossings have been tried or proposed. Many such devices are reviewed with evaluations of their effectiveness, if any were available. The "Monon green light" signal, several of which are in Indiana, was field observed for effectiveness and recommendations are made for improvements.

A study of speed profiles of vehicles approaching a crossing protected by a standard flashing light system is also reported. A photographic data collection system was developed which allowed determination of vehicle speed profiles, thus indicating driver reaction to the crossing condition. Speed profiles for non-actuated and actuated signal conditions are analyzed. It was determined that drivers approaching the crossing under progressively greater stimulus relative to an approaching train entered the approach at correspondingly slower speeds.

Reviewer's Comments:

This study was the first phase of the study reported by Russell (1974), and consisted of the collection of "before" speed profile data at a high-accident rural grade crossing in Indiana. As part of his report, Butcher reviews a large number of innovative active devices that had either been tried or proposed for use in various locations around the country. These devices included such things as red flashers, yellow flashers, neon signs, illuminated signs, variable message signs, in-vehicle real time warning, blinking lights, rotating lights, and the like. Of those devices that had been implemented, some seemed to produce positive results, and others not. In most cases, however, their effectiveness had not been evaluated. One of these devices, the "Monon Green" signal, was studied by Butcher and appears to be effective, according to Russell (1974), but no definitive evaluation has been conducted to date. It consists of a regular "Stop" sign supplementing the crossbuck on each side of the crossing. The sign is accompanied by a green traffic signal head and a sign saying "When light is OUT." The light is tied into the railroad's block system circuits.

The Butcher report is primarily useful as a supplement to the Russell report, which presents the results to the overall program.

Carmody, D. J., Lighted Crossings are Safe, Rural and Urban Roads, September 1966, 90-91.

Reviewer's Comments:

A field test in Modesto, California is described in which three low-volume, high nighttime use problem grade crossings were brightly illuminated with high intensity mercury vapor luminaires--much more brightly lit than adjacent intersections, as a matter of fact. This lighting was shown to reduce accidents dramatically, and the city plans to add lighting to nine additional crossings.

Mitchell, R., Identifying and Improving High Accident Locations, Public Works, Vol. 103, No. 12, 1972, 75-76.

Published Abstract:

This article describes methods used by the traffic engineering section of the city of Concord, California, to identify high-accident locations, and to determine the major hazards of these locations. Improvements which resulted in a reduction of accidents the year following their execution, are as follows: signal installation or modification, 22 percent reduction; delineation stripping, 21 percent; pavement markings, 35 percent; and increased enforcement, 48 percent; improved sight distance, 67 percent; and flashing beacons, 27 percent.

Reviewer's Comments:

This article is of interest in that it describes an example of an accident reduction traceable to the installation of flashing beacons.

Russell, Eugene R., Analysis of Driver Reaction to Warning Devices at a High-Accident Rural Grade Crossing, Purdue University, Indiana State Highway Commission, Joint Highway Research Project Report 74-16, August 1974.

Published Abstract:

The objectives of this research were to analyze the effect on motorists of improving the warning devices at a high-accident, rural grade crossing, from 8-inch[*] flashers to automatic gates and 12-inch[*] flashers activated by a Marquardt speed predictor and having additional strobe lights; to evaluate suitable parameters to make the analysis; to study accident history and site conditions and relate these to motorist reaction to the system--before and after; and to evaluate the data collection system itself.

Spot speeds were taken at eight points on each approach to obtain an approach speed profile for various groups under various conditions after the signal system was improved. These were compared to similar data taken before system improvement.

It was shown that an activated gate arm can be as effective in slowing the average approaching vehicle as a train across the road. Train and signal conspicuity were a problem and contributed to the poor accident record of older drivers. The Strobe lights made the warning system more visible after activation.

Most drivers approach a grade crossing safely and mean speed of various groups shows trends but is a relatively weak parameter to test effectiveness, because they do not isolate the occasional unsafe driver. Percent reduction of "fastest" cars, along with examining individual "fastest" cars, is a better parameter than mean speeds and decelerations to show improved effectiveness.

Reviewers Comments:

This report contains a good review of the literature regarding rail-highway grade crossing safety, and also describes driver

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[*] 8 inches = 20.3 cm
12 inches = 30.5 cm

response to upgrading the warning system at a high-accident rural grade crossing between a single track and a four-lane, 65 mph* (posted) highway.

In the before condition, the crossing had two sets of eight-inch* flashers and reflectorized crossbucks, plus the standard advance warning signs (with flashing amber construction lights affixed to them) plus pavement markings. The after condition, consisted of full-width gate arms with the standard lantern-type red lights mounted on them plus six red strobe lights fastened on each arm. In addition, 12-inch* flashing red lights were cantilevered over each lane (and on the shoulders as well for the southbound traffic). New reflectorized advance warning signs were installed (without the amber flashing lights) and the standard pavement markings remained unchanged. The gate arms, flashers, arm lanterns and strobes were all activated by a Marquardt Speed predictor. Before and after speed profile data were obtained. The "before" data were collected (in another study) one year prior to the upgrading, and the "after" data were obtained three weeks after the change-over. The highway ADT was 10,000 and the rail volume was six irregularly-scheduled freight trains per day. Film was used to record drivers approaching the crossing from each direction, and in conjunction with fixed reference markers was used to derive approach speed profiles from 1162 feet* out up to 77 feet* from the crossing. All data were collected during daylight hours (a possible constraint on the generality of the data). Before data were based on an analysis of 520 vehicles, while after data were based on 261 vehicles; however, direct comparisons between before and after driver behavior were possible for only 78 before vehicles and 61 after vehicles, both relatively small samples.

As suggested by the published abstract, the results of the before-after comparison were less than definitive. Speed and deceleration data did not clearly discriminate before and after driver behavior, although the approach speeds appear to be lower when more stimuli are present--such as a train across the track or a gate down. Also, the raised gate arms gave the crossing greater visibility, leading

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* 65 mph = 104 km/hr
8 inches = 20.3 cm
12 inches = 30.5 cm
1162 feet = 354.4 meters
77 feet = 23.5 meters

to lower mean approach speeds. "Personal observations" suggested that the strobe lights were the most alerting aspect of the new system; however, because so many changes to the crossing system were made at the same time, it was not possible to isolate the effect of any single element, such as the strobe lights. In general, the major contributions of the study lie in its development of a data collection technique, and in pointing out the difficulties in collecting definitive data in this area.

Schoppert, D. W. and Hoyt, D. W., Factors Influencing Safety at Highway-Rail Grade Crossings, Highway Research Board, National Cooperative Highway Research Program Report No. 50, 1968.

Published Abstract:

In 1961 motor vehicle accidents at highway-rail grade crossings numbered 2,931. In the accidents, 1,173 people were killed and 3,031 people were injured. The highway fatality rate at highway-rail grade crossings is disproportionately high when compared to the national total. Furthermore, almost one-third of the accidents occurred at crossings protected by audible and/or visible signals, 56 occurred despite lowered gates, and 88 occurred in the presence of trainmen or watchmen. It was with these thoughts in mind that this project was initiated by action of a joint committee of the American Association of State Highway Officials and the Association of American Railroads meeting in Miami, Florida, on December 6, 1962. Experimental and conventional signs for crossing protection were designed, installed, and tested in the field. A motion picture of the signs installed in the field was made and a group of engineers subjectively rated the experimental signs. Research findings include the development of a mathematical model for predicting accidents. The model was based on accident data obtained from a wide variety of private sources, state highway departments, and regulatory agencies. From the Interstate Commerce Commission the investigators obtained more than 15,000 accident reports spanning a five-year period. Warrants and criteria for the improvement of railroad crossings are presented in a graphic form.

Reviewer's Comments:

This report stands as the first comprehensive analysis of highway-rail grade crossing accidents conducted. It covers a number of areas, discussing qualitative factors as well as quantitative variable influencing crossing accident experience. Included as an appendix is the first thorough evaluation of the human factors considerations in grade crossing warning systems. It serves as a valuable resource document, and one that has stimulated much of the research in this area since 1968.

Schultz, T. G., Berg, W. D. and Oppenlander, J. C., Evaluation of Rail-Highway Grade Crossing Protection in Rural Areas, Highway Research Record, No. 272, 1969, 14-23.

Published Abstract:

The purposes of this study were to analyze the effects of environment, geometric characteristics, and highway and railroad traffic patterns with respect to grade crossing accidents in rural areas, and to develop warrants for protective devices at rural grade crossing. Comparison was made of 289 grade crossings that had experienced one or more accidents and 241 randomly selected non-accident grade crossings. Regression analysis was used to develop a model for predicting relative hazard for the sample locations. Relative hazard was expressed as a function of average daily highway traffic, average daily train traffic, roadside distractions, pavement width, and number of tracks. Modification of the model permitted development of warrants for selecting the recommended type of protective device for crossings in rural areas. These warrants are predicted on protection levels currently employed at crossings in Indiana.

Schultz, T. G., *Evaluation of Safety at Railroad-Highway Grade Crossings*, Purdue University and Indiana State Highway Commission, Joint Highway Research Project Report No. 9, September 1965.

Published Abstract:

One purpose of this research investigation was to analyze the effects of environment, topography, geometry, and highway and rail traffic patterns with respect to rail-highway grade crossing accidents in rural areas. The mathematical tools of factor analysis and regression analysis were used to develop models for predicting the relative hazard at a railroad grade crossing. These models are based on rail volume, highway volume, and roadside distractions, such as houses, businesses and advertising signs. To evaluate the proposed mathematical relationships, it was necessary to collect sufficient data on many variables deemed to have an influence on safety. Therefore, 56 variables were measured at the 289 accident locations and 28 variables at the 241 non-accident locations. Previous research efforts were concerned either with long period accident experience or with before-and-after studies of the various protection devices. In this research, locations which experienced accidents in a two-year period were compared to non-accident locations. The results of this study can be used to determine the type of protection which a crossing warrants.

References Concerning Technical Innovations

1) Aurelius, J. P., Korobow, N., The Visibility and Audibility of Trains Approaching Rail-Highway Grade Crossings, NTIS (PB202-668).

2) Diffley, G., Rear-End Collision Stopper, Human Factors Bulletin, pp 8, 9, April 1975.

3) Endmann, K., The Problems of Calculating Response Intervals for Flashing Lights (and Gate Protection) at Railway Grade Crossings, Columbus, O.: Battelle Memorial Institute, Report BCL-473, 1966.

4) Goldrath, B., S-F's Yellow Cabs Test "Cyberlite," Commercial Car Journal, Vol. 124, No. 3, pp. 100-101, 1972.

5) Holmstrom, F. R., Installation and Characteristics of High-Intensity Xenon Flashlamps at Railroad-Highway Grade Crossings, Presented the Annual Meeting of the Association of American Railroads, New Orleans, La., September 1975.

6) Hopkins, J. B. and Holmstrom, F. R., Toward More Effective Grade-Crossing Flashing Lights, Presented at the 54th Annual Meeting of the Transportation Research Board, Washington, D. C., January 1975.

7) Hopkins, J. B., Hazel, M. E., Technological Innovation In Grade Crossing Protective Systems, Report No. DOT-TSC-FRA-71-3, Department of Transportation, June 1971.

8) Hopkins, J.B. and Newfell, Guidelines for Enchancement of Visual Conspicuity of Trains at Grade Crossings, FRA-OR & D-75-71, May, 1975.

Aurelius, J. P. and Korobow, N., The Visibility and Audibility of Trains Approaching Rail-Highway Grade Crossings, New York, N. Y.: Systems Consultants, Inc., Report No. FRA-RP-71-2, May 1971.

Published Abstract:

This study investigates devices and color schemes, proposed or in use on locomotives, which serve to make the train visible or audible to motorists approaching grade crossings.

A color scheme using two contrasting colors, each color at least $3\frac{1}{2}$ x 5 feet* in area, is recommended for visibility at 1000 feet.* One color should be very bright, such as fluorescent or bright yellow. Two high-output xenon strobe lamps are recommended, one on each side of the cab roof, to flash alternately whenever the train is moving. At night, lighted panels are recommended as supplements to the strobe lamps.

The sound level required to reliably alert a motorist was found to be 105 dB just outside the vehicle. In high speed encounters, present horns cannot reliably warn motorists early enough. A horn with enough output to be totally effective would be an unacceptable nuisance.

The report includes a bibliography and tables of required ranges.

Reviewer's Comments:

This report is of value not only because it points out the futility of utilizing conventional approaches to providing auditory warnings to the motorist, but also because it demonstrates the improvement in train conspicuity through the use of both bright colors and strobe lights on the locomotive.

The authors point out that strobe lights "are approximately five times greater in signaling effectiveness than are fixed sources of light of equal intensity" (p. 39). They also state that xenon strobe lights provide greater penetration through fog, rain and snow. Another point

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* 3 1/2 feet = 1.1 meters
5 feet = 1.5 meters
1000 feet = 305 meters

made in the report is that pairs of lights provide a better cue for distance estimation than does a single light. Pairs of strobe lights, the report continues, serve to alert motorists by providing apparent movement, extremely effective light output, and a wide angle of view.

A field evaluation of various types of lights mounted on the roofs of locomotives was made during daylight, dusk and at night. Observations were made from a distance of 300 feet* of a locomotive crossing the road at low speed with one or another of the devices actuated.

The following summarizes the models tested and the results:

1. Prime Manufacturing Corp., Oak Creek, Wisconsin: Model 8900. This light uses three 75 watt sealed-beam lamps which are flashed sequentially to simulate rotation without moving parts. This device was judged poor in daylight because the fixed-position lamps did not provide full brightness at all angles. An observer not positioned in just the right spot did not receive visual impact.
2. Pyle 15360 'Roof Gyralite'; Trans-Lite Inc., Milford, Connecticut. This light has a sealed-beam lamp in its upper dome, which is aimed down on a wedge-shaped reflector which is rotated. It provided good visual impact in daylight.
3. Safety Products Co., Chicago, Illinois. No model number. A strobe lamp, using a thin ring-shaped flash tube concentric with a reflector that resembles two cones stuck together at the apexes. The light output of this unit was too small to be effective in daylight.
4. Western-Cullen Division, Federal Sign and Signal Corp., Chicago, Illinois: Model D-312. Two 75 watt sealed-beam incandescent lamps mounted back-to-back

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* 300 feet = 91.5 meters

and rotated by a motor. This lamp was not tested at Essex, but it was examined and judged likely to be effective in daylight.

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

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

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

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

The above are all daylight evaluations. All devices had high visual impact at dusk and at night.

Diffley, G., Rear-End Collision Stopper, Human Factors Bulletin, pp. 8, 9, April 1975.

Reviewer's Comments:

This article discusses a new brakelight concept called "Cyberlite," developed by John Voevodsky. Cyberlite is a foot-long amber light mounted on the rear of passenger cars that flashes at a frequency varying directly with the force applied to the brake pedal. Actually, the frequency varies with the deceleration rate of the vehicle. A field test of Cyberlite on a taxicab fleet in San Francisco appeared to show a reduction in the number of accidents in which these cabs were rear-ended.

The concept of variable frequency may be useful when applied to the crossing problem. For example, crossing lights may flash with ever-increasing frequency as the train nears the crossing.

Endmann, K., The Problems of Calculating Response Intervals for Flashing Lights (and Gate Protection) at Railway Grade Crossings, Columbus, O.: Battelle Memorial Institute, Report BCL-473, 1966.

Published Abstract:

The length of the response interval for flashing light signals to be activated depends upon the approach time of the highway vehicle, the speed of the train and the relationship between certain signaling and operational conditions. For safety reasons, the fastest train speed is used for calculating the response interval. Slower trains and trains that stop before the crossing can produce inordinately longer waiting times for the highway user leading to annoyance and, ultimately, disregard for the signal. This can be avoided by making the response interval sensitive to the speed of the train. This article describes how this is done presenting mathematical equations, charts and tables of data.

Goldrath, B., S-F's Yellow Cabs Test "Cyberlite," Commercial Car Journal, Vol. 124, No. 3, pp. 100-101, 1972.

Published Abstract:

The Yellow Cab Company of San Francisco has installed on 350 of its taxis a center-mounted rear light that flashes when the driver applies his brakes. The pulse rate of 1-7.6 flashes/second is a function of the abruptness of brake application. In the five years preceding installation of the system, the company's rear-end collision rate was 16 monthly; in the first full month the rate among the cyberlite-equipped group fell to 2.6. In addition, over the first three months of testing the average cost per accident dropped from $305 to $35. The lights were initially set for a maximum brightness of 1700 candlepower. Because of complaints this was reduced to 600, and the collision rate immediately rose from one in two weeks to six. A compromise was reached at 1200, which has been followed by a level rate of one rear-end collision per week.

Reviewer's Comments:

The relevance of this article to the current study is that the variable frequency concept may have application to grade crossing safety, by linking flashing lights frequency to the proximity of the train to the crossing.

Holmstrom, F. R., Installation and Characteristics of High-Intensity Xenon Flashlamps at Railroad-Highway Grade Crossings, Presented at the Annual Meeting of the Association of American Railroads, New Orleans, La., September 1975.

Reviewer's Comments:

This paper presents a thorough discussion of xenon strobe lights and their applicability to the grade crossing signalling problem. Both theoretical advantages and experiences gained from actual field installations are discussed. A strong argument is presented in favor of the use of xenon strobe lights, similar to the Hopkins and Holmstrom paper (1975). Both papers combine to present very valuable resource information for the present project. Techniques for using xenon flashlamps are detailed, together with a rationale for their effectiveness. The two papers together represent the current state-of-the-art with regard to using strobe lights for crossing warnings.

Hopkins, J. B. and Holmstrom, F. R., Toward More Effective Grade-Crossing Flashing Lights, Presented at the 54th Annual Meeting of the Transportation Research Board, Washington, D. C., January 1975.

Published Abstract:

Pairs of alternately-flashing red incandescent lamps have formed the primary motorist warning device at grade crossings for several decades. Although significant evolutionary improvement has occurred, basic constraints--on power consumption, in particular--have limited the total effectiveness normally found. Tightly focussed beams, necessary to obtain high intensity at low power levels, make perceived brightness highly dependent upon both motorist position and precise alignment, which is difficult and expensive to maintain.

Examination of appropriate literature and existing standards has made possible delineation of functional specifications and desirable characteristics of motorist warnings for use at grade crossings. Consideration of relevant lighting technology shows that significant improvement is possible through the use of xenon flash lamps in standard crossing mountings, used in place of--or in concert with--conventional lights. The short-duration flash of the xenon unit appears to offer a warning of markedly greater alerting effectiveness. This result is obtainable with little deviation from the basic framework of applicable standards, motorist familiarity, and conventional equipment. This study includes discussion of optimal specifications, relevant technology, compatibility with existing systems, and field tests.

Reviewer's Comments:

This paper represents a very thorough examination of the problem of providing effective flashing signals for crossings, based on research by others as well as that conducted by the authors at the Transportation Systems Center. Very informative discussions are presented concerned with lens color (shades of red), intensity, flash rate, beam width, duty cycle and the like. A strong argument is presented for the use of xenon strobe lights to produce a more effective warning system, based upon their superior alerting qualities and their low power consumption. In addition, the authors state that a relatively broad beam pattern is possible with xenon strobe lights due to their short-duration flashes, and they recommend the installation of such lights as a supplement to existing protection.

Hopkins, J. B. and Hazel, M. E., Technological Innovation in Grade Crossing Protective Systems, Cambridge, Mass.: Transportation Systems Center, U. S. Department of Transportation, Report No. DOT-TSC-FRA-71-3, June 1971.

Published Abstract:

The constraints on innovative grade crossing protective systems are delineated and guidelines for development indicated. Inventory data has been arranged to permit an estimate of the classes of systems needed, the allowable costs, and contribution of various types of crossings to accidents. Many crossings warrant very limited expense and account for very few deaths. A number of approaches are possible for the intermediate cost classes, based on use of conventional signals with low-cost activation systems. Use of similar elements, singly or in combination, can also improve effectiveness of more expensive systems. The very high cost locations may well benefit from interconnection of train and vehicle detectors and small computers.

Extensive analysis and laboratory investigation has been carried out relating to a microwave telemetry alternative to conventional track circuits and possible crossing-located radar and impedance train detection systems.

Reviewer's Comments:

This paper is of general interest to the current project. It gives general functional requirements for grade crossing warnings of conspicuity, clarity (unambiguity), and credibility, points out the need for high reliability for any device used and questions whether the "fail-safe" requirement has, in fact, stifled the development of more effective and cost-effective systems. Finally, the paper points out the desirability of incorporating the grade warning system into the general highway system of utilizing traffic control devices to provide continuity, logic and uniformity, where possible.

Hopkins, J.B. and Newfell, Guidelines for Enchancement of Visual Conspicuity of Trains at Grade Crossings, FRA-OR & D-75-71, May, 1975.

Reviewer's Comments:

This study recommends a pair of clear ("white") xenon flash-tube beacons mounted on opposite sides of a locomotive cab roof together with amber incandescent lamps outlining the locomotive as the "preferred" system to enhance the visual conspicuity of the train locomotive. The authors recommend a nighttime effective intensity of 100-400cd with a daytime effective intensity of 800-4000cd. Further recommendations include alternately flashing the two xenon flash tubes at a combined rate of 1.5 - 3.0 times per second.

References Concerning Driver Behavior Approaching a Railroad Crossing

1) Hartsell, C. I., *Conduct Study with the View Toward Developing Alternate Types of Automatic Crossing Protection*, AM Railway Engineering Association Bulletin, Vol. 73, Bulletin 635, 1973, pp 196-197.

2) Heathington, K. W. and Urbanik, T., *Driver Information Systems for Highway-Railway Grade Crossings,* Highway Research Record, No. 414, 1972, 59-77.

3) Sanders, J. H., *Driver Performance Factors in Countermeasure Development at Railroad-Highway Grade Crossings*, Paper presented at the 54th Annual Meeting of the Transportation Research Board, Washington, D. C., January 1975.

4) Sanders, J. H., *Speed Profiles and Time Delay at Rail-Highway Grade Crossings*, Falls Church, Va.: BioTechnology, Inc., May 1972.

5) Van den Branden, B., Blackwell, H. R., Treiterer, J., *A Study of Stop Warning Systems,* Ohio State University, Ohio Department of Highways, HPR Project, 1967, 30 pp.

6) Urbanik, T., II, *An Evaluation of Safety at Highway-Railway Grade Crossings*, Final Report, Purdue and Indiana State Highway Commission, JHRP-11, 1971, 163 pp.

Hartsell, C. I., Conduct Study With the View Toward Developing Alternate Types of Automatic Crossing Protection, American Railway Engineering Association Bulletin, No. 623, p. 153, November 1969.

Published Abstract:

There have been numerous reports and investigations which repeatedly stress the need for increased warning to highway vehicles of an approaching train at a grade crossing. To accomplish this end, various railroads are experimenting with the following items: (1) a high-intensity, quartz-iodine cycle lamp bulb requiring 10 volts, 36 watts, compared to the standard 10-volt, 18-to 25-watt installation. Some railroads use 25-watt lamp bulbs as standard in their flashing-light signals, (2) a high-intensity 10-volt, 18-watt aluminized lamp bulb, (3) various types of "hot spot" roundels which are available for flashing-light signals, and (4) redesigned shallow signal lamp housings which are now available. A majority of the railroads trying out these devices are reserving their comments and recommendations until their experiments have been concluded.

Reviewer's Comments:

This article suggests several alternate bulb types for use in flashing signals. A followup survey of the experience of those railroads trying out the new bulbs would be of interest.

Heathington, K. W. and Urbanik, T., Driver Information Systems for Highway-Railway Grade Crossings, Highway Research Record, No. 414, 1972, 59-77.

Published Abstract:

The first objective of this research was to evaluate driver attitudes concerning hazards at highway-railway grade crossings. Respondents considered highway-railway grade crossings relatively more hazardous than other potential highway hazards but considered none of the potential hazards to be very serious. The second objective was to evaluate the economic priorities for improving railroad grade crossings relative to eight other highway improvements. Respondents considered safety at highway-railway grade crossings to be very important. The third objective was to evaluate driver preferences for information systems to be used at highway-railway grade crossings. An overhead changeable-message sign was the most preferred alternative method of warning. The fourth objective was to evaluate driver preferences for messages to be used in an information system for highway-railway grade crossings. The respondents preferred information even when no train was present and preferred full words rather than abbreviations.

Sanders, J. H., Driver Performance Factors in Countermeasure Development at Railroad-Highway Grade Crossings, Paper presented at the 54th Annual Meeting of the Transportation Research Board, Washington, D. C., January 1975.

Published Abstract:

This paper summarizes the findings of "Human Factors Countermeasures to Improve Highway-Railway Grade Crossing Safety," a field demonstration study to determine the requirements for grade crossing accident countermeasures.

Information was obtained on driver behavior, knowledge, and attitude using the Traffic Evaluator System, time-lapse photography, and questionnaires. A review of the safety related factors brought to the grade crossing situation by the driver was also made. The review included licensing and education, safety programs, attitude and habit, and driver/vehicle capabilities and limitations. An extensive analysis of these data suggested countermeasures concepts and determined target populations for countermeasures intervention.

Behavior measures were isolated which may be used to discriminate among candidate countermeasures when applied in the field evaluation program plan presented in the study.

Reviewer's Comments:

This paper is a summary of a report by Sanders, Kolsrud and Berger*. A review of human factors aspects of crossing behavior was conducted, and emphasis is given to the role of expectancy, or set, and the need for high attention-getting warning devices. Field investigations of nine crossings (3 passive and 6 active) were made. Data collected included speed and acceleration data for all approaching vehicles within 500 feet* of the crossing, driver looking behavior, crossing signal activations, train arrival times and train speed. In addition, a selected sample

* 500 feet = 152.5 meters

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* Sanders, J. H., Kolsrud, G. S. and Berger, W. G., Human Factors Countermeasures to Improve Highway-Railway Intersection Safety, Falls Church, Va.: Biotechnology, Inc., June 1973.

of drivers were stopped and interviewed. Data were collected on 18,552 vehicles and 57 trains, and 1,267 drivers were interviewed. Among the findings:

1. Drivers slow for crossings because they are bumpy (speed reduction increases with increased roughness).

2. Nearly one percent of the drivers stopped did not realize they had just driven through a crossing. The majority of the drivers knew the crossing location from previous experience, while the remainder detected it by means of the advance sign, the crossing protection, the rails or the pavement markings.

3. Drivers generally underestimated their speed by 30 percent, a dangerous tendency.

4. Drivers generally displayed an astounding lack of awareness of the characteristics of the crossing they had just been exposed to and/or of the meaning or prevalence of various types of crossing protection.

5. Warning time provided by signal activation at active crossings was highly variable.

6. A driver's crossing behavior can be adequately described by his looking behavior, his crossing speed, and his percent speed reduction approaching the crossing.

7. No consistent differences in driver behavior were found between active and passive crossings, except where severe sight restrictions (less than 150 feet* visibility) existed.

8. There were indications that driver awareness of law enforcement yields more careful behavior overall and tends to increase awareness in general.

9. High driver familiarity with a particular crossing was shown to reduce looking behavior and the percent of speed decrease over that of very unfamiliar drivers.

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* 150 feet = 45.8 meters

In addition, a pilot effort was conducted to assess the effects of placing flashing lights on each side of the standard advance warning sign. These lights were found to reduce crossing speeds and increase looking behavior. However, Russell (1974) feels that this represented only a short-term modification of behavior. Also found was that this speed reduction and looking behavior was greater for a bright flashing light than for a dim light.

Sanders concludes by pointing out the need to develop performance measures for application to a variety of crossings whose characteristics differ from the ones used in his study.

Sanders, J. H., Speed Profiles and Time Delay at Rail-Highway Grade Crossings, Falls Church, Va.: BioTechnology, Inc., May 1972.

Published Abstract:

This report documents the results of a study aimed at defining the behavior of motorists in the vicinity of railroad grade crossings. Crossing parameters of urban/rural, two/four lane, high/low volume and active/passive grade crossing protection were considered in the final selection of 26 crossings for instrumentation. At each site, the highway was instrumented at five points in each lane using the Traffic Evaluator System. The resulting magnetic tape permitted determination for each of over 40,000 vehicles at each point, speed, lane changing behavior, headway, wheelbase and number of axles. Manual inputs were made to the system to indicate vehicles which were required to stop at the crossing, the activation of protective devices, the arrival and departure of trains, and train speed. The results showed that motorists reduce their speed more at crossings that have passive warning devices than at crossings afforded train-activated devices.

Reviewer's Comments:

This study developed a technique (Traffic Evaluator System") for measuring speed, lane change behavior, headway, wheelbase and number of axles for vehicles approaching and passing through a crossing. Data on over 40,000 vehicles at 26 crossings were collected, with additional information on actuation of signals, train presence and train speed. Speed profile data from passenger cars that did not have to stop led to the following conclusions, among others:

1. Speed reduction approaching crossings varied directly with the roughness of the crossing.

2. Speed reductions were greater and occurred sooner for passive crossings than for crossings protected by active devices.

3. Less speed reduction occurred at rural crossings than at urban crossings, regardless of the type of protection.

4. Seven cars crossed while signals were flashing, possibly due to excessive warning time.

Van den Branden, B., Blackwell, H. R. and Treiterer, J., A Study of the Relative Effectiveness of Selected Stop Warning Systems, Columbus: The Ohio State University, Engineering Experiment Station, March 1967.

Published Abstract:

A coordinated study of stop-warning systems was conducted which included the following elements: (1) a statistical study of the effectiveness of different stop-warning systems in reducing the rate of accidents at rural intersections in Ohio; (2) a simulator study of the visual conspicuity of the flasher elements of stop-warning systems; (3) a field study of traffic stream characteristics at intersections equipped with different stop-warning systems; and (4) a photometric survey of luminances at intersections equipped with different stop-warning systems.

It was shown that the order of effectiveness of four stop-warning systems was precisely the same for: (1) the extent to which the rate of accidents was reduced after installation of the systems; and (2) the visual conspicuity of the flasher elements of the systems as measured in a highway simulator.

The photometric survey did not prove useful due to the large variability of luminance ratios among elements of the stop-warning systems and their natural backgrounds related to the time of day. Although successful assessment of speed profiles was achieved by both pneumatic tube and photoelectric detector systems, it was not possible to interpret the deceleration profiles which were obtained at different intersections in terms related either to accident reduction or the visual conspicuity of elements of stop-warning systems.

The most effective stop-warning system of those investigated involved an 8-inch* flasher mounted on a stop sign along each side of the roadway, with the two flashers synchronized. Of the systems involving overhead mounted 8-inch* flashers, the most effective involved four flashers with pairs at the same height in the two highway lanes flashed in synchrony, and with vertical alternation between two pairs at

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* 8 inches = 20.3 cm

different heights. The use of 12-inch* instead of 8-inch* flashers resulted a marked increase in effectiveness. For example a pair of 12-inch* flashers mounted overhead in the two lanes at the same height and flashing synchronously were slightly more effective than the two pairs of 8-inch* flashers described above. Additional variants of stop-warning systems should be evaluated to establish the generality of the present conclusions.

Reviewer's Comments:

The stop-warning systems studied included both overhead and roadside flashing red signals, both 8-inch* and 12-inch.* The number, placement and size of the flashing signals were varied in the study. Forty-eight inch "Stop" signs were also used, in conjunction with the lights. The flasher frequency was approximately 60 per minute.

The simulator study involved a 1:24 scale version of a highway, simulating an overall length of 1,320 feet.* The simulator data were derived from numerous tests of two subjects, while the field accident data were collected from six rural intersections. Night conditions were simulated, and subjects viewed the signals through a veiling glare.

The results of the study are of interest because they suggest that ground-mounted flashers may be more attention-getting than overhead flashers, and that 12-inch* flashers are more conspicuous than 8-inch* flashers. Because of the small sample sizes and experimental nature of the study, the results are not to be considered definitive.

* 12 inches = 30.5 cm
8 inches = 20.3 cm
1320 feet = 402.6 meters

Urbanik, T., An Evaluation of Safety at Highway-Railway Grade Crossings, Final Report, Purdue University and Indiana State Highway Commission, Joint Highway Research Report JHRP-11, 1971.

Published Abstract:

An attitudinal survey was used to evaluate driver attitude concerning the hazard at railroad grade crossings, citizen appraisal of properties for improving grade crossing safety, driver evaluation of possible warning systems for crossings, and the development of the general design of a proposed new advance warning system. The research indicates that the respondents considered railroad grade crossings more hazardous than several other highway hazards. However, all hazards were, at most, only considered moderately hazardous. The improvement of safety at railroad grade crossings was given high priority by the respondents. An overhead changeable message sign was the most preferred method of warning at railroad grade crossing. It was concluded that a field installation is desirable.

Reviewer's Comments:

The above abstract is self-explanatory. This paper has minimal relevance to the conduct of the present study.

References Concerning
Sound Stimuli

1) Cox, J. J., Road-Rail Protection - *Audible Warning Effectiveness*, Proceedings, Australian Road Research Board, Vol. 6, Part 2, 1972, 448-466.

2) Longrigg, P., *Railroad-Highway Vehicular Movement Warning Devices at Grade Crossings,* IEEE Transactions on Industry Applications, Vol. 1A-11, No. 2, 1975, pp 211-221.

3) Plummer, R. W., Armstrong, W. D. and King, E. L., *An Investigation of the Effects of Reinforced Stimuli on Driver Brake Reaction,* Proceedings, Annual Meeting of the Human Factors Society, October 1974.

Cox, J. J., Road-Rail Protection - Audible Warning Effectiveness, Proceedings, Australian Road Research Board, Vol. 6, Part 2, 1972, 448-466.

Published Abstract:

Audible warning is becoming progressively less effective with modern high speed road traffic and noisy vehicles interfering with reception. Subjective examination of warning sounds can be misleading as the ear does not directly compare sound pressure levels. Sound reduces in intensity in accordance with the inverse square law. To double the range of hearing, a fourfold increase in pressure level is required. Suggestions are made on changes in methods of road vehicle operation which would take into consideration high winds and other factors and improve overall safety on crossing approaches. Suggestions are also made on improvements to roadside audible warnings and standardization of audible signals that it would be practical to carry out without degradation of the total environment. It is concluded that audible warnings still play a vital part in road-rail protection. In many instances revised motor vehicle operation could lead directly to a substantial reduction in the serious type of collision with high noise level road transports during periods of high winds, and an overall improvement in protection levels.

Reviewer's Comments:

This is a position paper supporting the use of auditory warnings for crossings, in contrast to the position of Aurelius and Korobow, among others. There is little relevance to the present study.

Longrigg, P., Railroad-Highway Vehicular Movement Warning Devices at Grade Crossings, IEEE Transactions on Industry Applications, Vol. IA-11, No. 2, 1975, 211-221.

Published Abstracts:

A system of vehicular movement warning devices is described that might improve to some extent the safety of grade crossing operations. Two methods are detailed. One involves static directional sonic devices positioned at the crossing; warning activation is made on a real-time closing velocity determination. The other system employs a special variety of cattle guard in the roadway, to issue a tactile warning. Both systems are designed to give adequate warning to a motorist in a critical encounter situation as he approaches the crossing with a convergent locomotive on the tracks. A bonus feature in the use of selectively activated static directional sound warning sources would be the curtailment of urban noise levels, where trains presently use the mobile audible source to issue warnings.

Reviewer's Comments:

This paper provides a good discussion of motorist behavior patterns at crossings. The author analyzes a critical encounter at a crossing and comes with the two approaches indicated above - sonic devices and rumble strips. He also suggests the use of liquid crystal displays deployed across dangerous grade crossings to give continuous information about the status of the crossing. LCD's use little power, and the color can be varied. Longrigg also suggests the use of polarized light as a possibility.

Plummer, R. W., Armstrong, W. D. and King, E. L., An Investigation of the Effects of Reinforced Stimuli on Driver Brake Reaction, Proceedings, Annual Meeting of the Human Factors Society, October 1974.

Published Abstract:

The purpose of this research was to investigate what effect added light and sound stimuli, placed inside an automobile, would have on a driver's braking performance. The research was designed to determine whether a driver's brake reaction time could be decreased by reinforced stimuli and, if so, which type of the stimuli tested would be most significant in improving a driver's reactions. The research was conducted on an open section of interstate highway under normal driving conditions. Two vehicles were used in the tests. The subjects' test vehicle was equipped with a light and sound stimulus attached to the dashboard. The subjects in this second vehicle were instructed to respond immediately to the activation of the lead vehicle's brake lights by depressing the brake pedal of their vehicle. In addition, the subjects were instructed to immediately respond to the activation of the light and/or sound stimulus by depressing the brake pedal. Each time the brake lights of the lead car were activated one of three conditions would occur: (1) neither the sound nor light stimulus in the subject's vehicle would activate, (2) either the light or sound stimulus would activate, or (3) both the light and sound stimulus would activate, in addition to the brake lights of the lead car. The reinforced stimuli inside the subject's vehicle could only be activated by the activation of the lead car's brake lights. The reaction times needed for the subject to respond to these stimuli were recorded. The test subjects were separated into two age groups: under thirty-five years old and over thirty-five years old. An analysis of variance showed that the age of the subject, the difference between subjects, and the type of stimulus were significant in influencing the brake reaction times. The sound stimulus caused the most significant decrease in brake reaction times.

Reviewer's Comments:

This article is of interest because it shows the value of redundant stimulation in producing shorter reaction times, suggesting that more and/or different signals at a crossing would produce more effective warning.

APPENDIX B

1.0 VISUAL PERCEPTION

A lot is known about the visual perception process, however, little of what is known finds its way into highway literature in the form of a layman's discussion. This Appendix is an attempt to partially fill this gap as well as provide self-containment of the document itself.

The design of the indoor laboratory experiment including the test facilities, testing techniques, subject selection, target selections and analysis of results were all performed with one eye focused on a number of important and proven facts concerning visual perception. In order to make this report more meaningful, a layman's discussion of some principles concerning vision, light, color and filters is in order (Judd, Ref. 1).

1.1 Electromagnetic Radiation

There are many types of radiators of electromagnetic energy, the one most familiar is the thermal radiator. Thermal radiators distribute energy across the infinite electromagnetic spectrum but most of their energy is concentrated in the region between microwaves and ultraviolet, sometimes called the "optical spectrum." The optical spectrum, see Figure B-1, is so named because energy radiated at these wavelengths is subject to the optical laws of reflection and refraction.

1.2 The Visual Spectrum

The "visual spectrum" is a very small part of the optical spectrum which is seen as light by the human eye. Light as seen by the human eye emanating from a source with a single electromagnetic frequency (in the visual spectrum) will be seen as a specific light color. Such a source is called a monochromatic source. In theory, a uniform spectrum of all visible electromagnetic frequencies is defined as a white light, however, the eye sees a lot of light

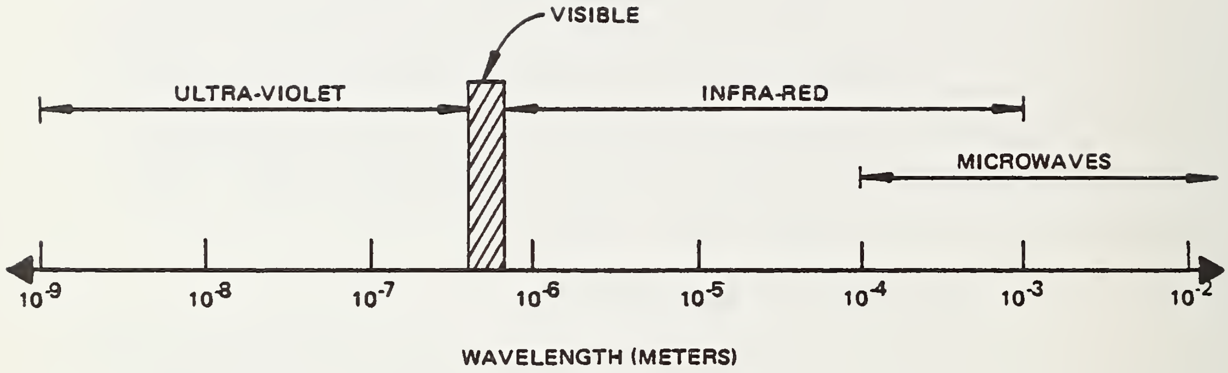

FIGURE B-1
OPTICAL SPECTRUM

sources as being white, even though the electromagnetic spectrum in the visible range deviates greatly in uniformity. What is white and what is not white light will also differ among observers. Although there are great differences in spectral sensitivity between individuals most people see electromagnetic wavelengths from 400 to 700 nanometers (nm) as light. Wavelengths longer than 700 nm are invisible infrared region radiation and those shorter than 400 nm are invisible ultra-violet region radiation.

1.3 The Human Eye

Light sensing is performed by a portion of the rear surface of the eye called the retina. The retina has two types of sensor cells called rods and cones. Light sensing impulses are transmitted from these cells to the rain through the optic nerve. Rods operate at the lower light levels but do not discriminate colors. Rods are most sensitive in the green region of the visible spectrum. Cones operate in the medium and higher light levels. They perform color discrimination as well as other recognition and sharp focus functions. They are most sensitive in the yellow region of the spectrum.

1.4 Color Vision

At normal light levels, most people see monochromatic radiation wavelengths of:

1) 400 nm to 424 nm as violet
2) 424 nm to 455 nm as indigo
3) 455 nm to 492 nm as blue
4) 492 nm to 575 nm as green
5) 575 nm to 585 nm as yellow
6) 585 nm to 647 nm as orange
7) 647 nm to 740 nm as red

The "photopic" curve, shown on Figure B-2, shows the great variation in eye sensitivity to various colors that people experience in daylight or a well-light environment. The "scotopic" curve in Figure B-2, shows how one's sensitivity to color changes when their visual system has adapted to darkness. The complex eye system which includes the rods, the cones, the iris and a process called "dark adaption" all enable the individual to see over a wide range of light levels. At lower light levels, when the iris has fully extended the diameter of the pupil, the retinal rods become most important. When light levels are first reduced, the sensitivity of the rods are quite low. However, the process called dark adaption increases the rod sensitivity a thousand fold in a few minutes and by more than a million fold in less than an hour. This slow adaptation is supplemented by another process called rapid neutral adaptation. Rapid neutral adaptation can increase the sensitivity of the eye by two hundred fold within one or two seconds after a sharp drop in light level. Sensitivity of the eye was discussed in great detail by Cole (Ref. 2).

Most night driving actually takes place in the mespotic range of adapted vision. Cole describes the light levels, associated with the mesoptic range as extending from moderate moonlight to just below the comfortable reading level.

With dark adaptation, the eye becomes more sensitive to the shorter wavelengths and less sensitive to the longer wavelengths. This change, known as the "Purkinje Shift," causes increased sensitivity to blues and decreased sensitivity to reds. This phenomena of increased sensitivity to blue at night is referred to throughout this document (Ref. 3).

There are many other important considerations affecting the visual process such as aging effects, visual acuity contrast and background luminance effects.

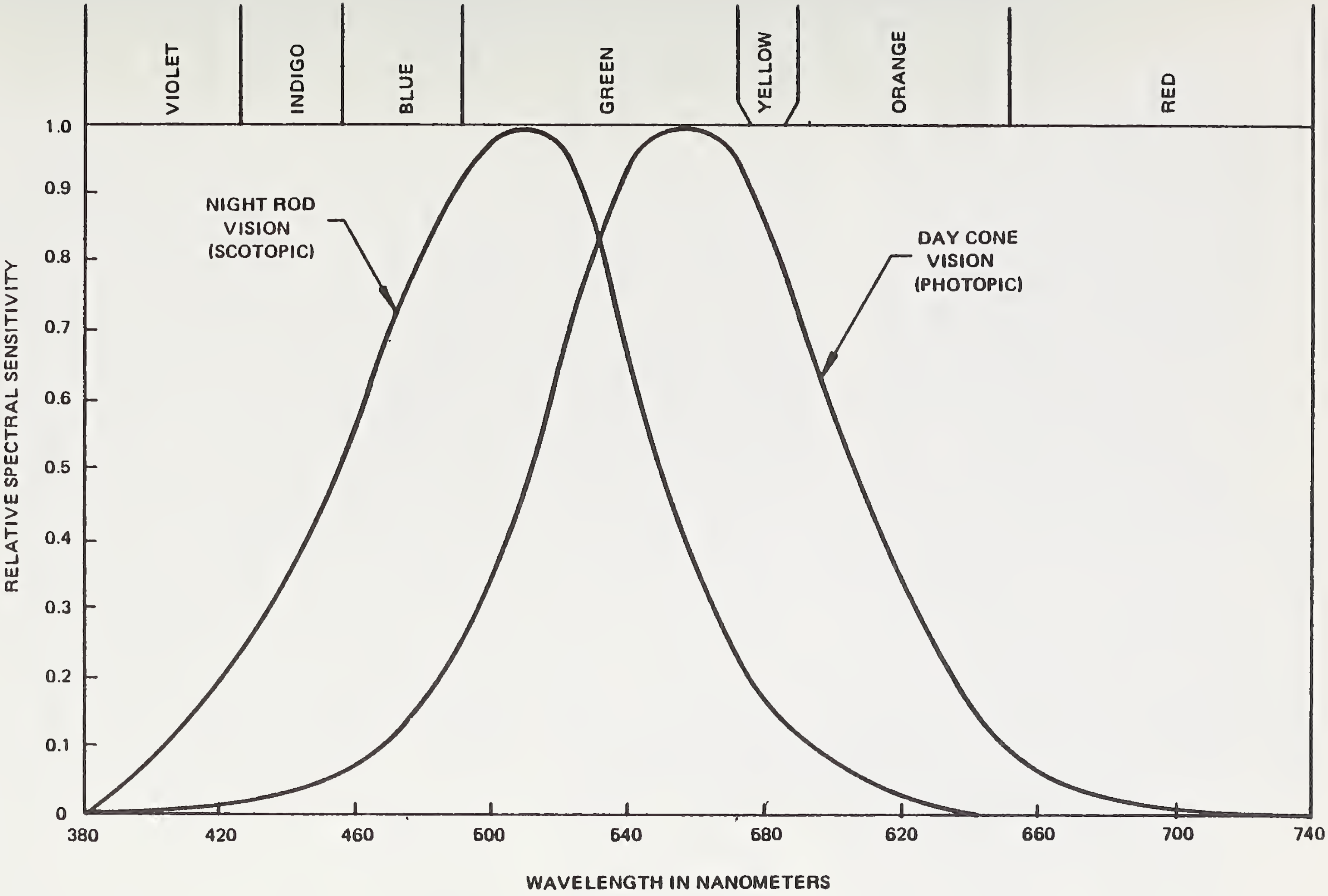

FIGURE B-2
SPECTRAL SENSITIVITY OF THE HUMAN EYE

1.5 Filters and Lenses

The function of a light filter is to inhibit light in certain portions of the visual spectrum. Usually colors or wavelengths pass through the filter with differing degrees of attenuation caused by partial absorbtion by the dyes in the filtering medium or lens. A traffic signal lens contains a dye composition that attenuates transmission of light in a manner to emphasize certain colors (less attenuation) and de-emphasis other colors (more attenuation) and may be thought of as a light filter). The filter or lens can be described functionally across the visible spectrum as to the degree to which wavelengths are attenuated.

To illustrate filter transmittance, or the degree to which a filter or lens attenuates visual electromagnetic energy, one must turn to a discussion of optical filtering (see Jenkins & White - Reference 4). A hypothetical filter transmittance curve (function) is shown in Figure B-3 and depicts the degree to which the filter attenuates visible wavelengths in the electromagnetic spectrum.

Lenses (filters) used in railroad flashing lights, traffic signals and other lights with highway applications are extremely inexpensive optical filters. They are typically wide band pass filters and are normally specified by three chromaticity coordinates (see Reference 5). Within highway literature these three chromaticity coordinates are also referred to as transmittance but these numbers do little to explain how a given lens attenuates a light source. Manufacture of these lenses to meet standards and specifications related to three chromaticity coordinate values is what makes the lenses inexpensive. Measurement of the transmittance (per Figure B-3) of a batch of similar clored lenses, manufactured for highway application and meeting the same chromaticity specifications, would certainly not produce a unique transmittance curve as that shown in Figure B-3.

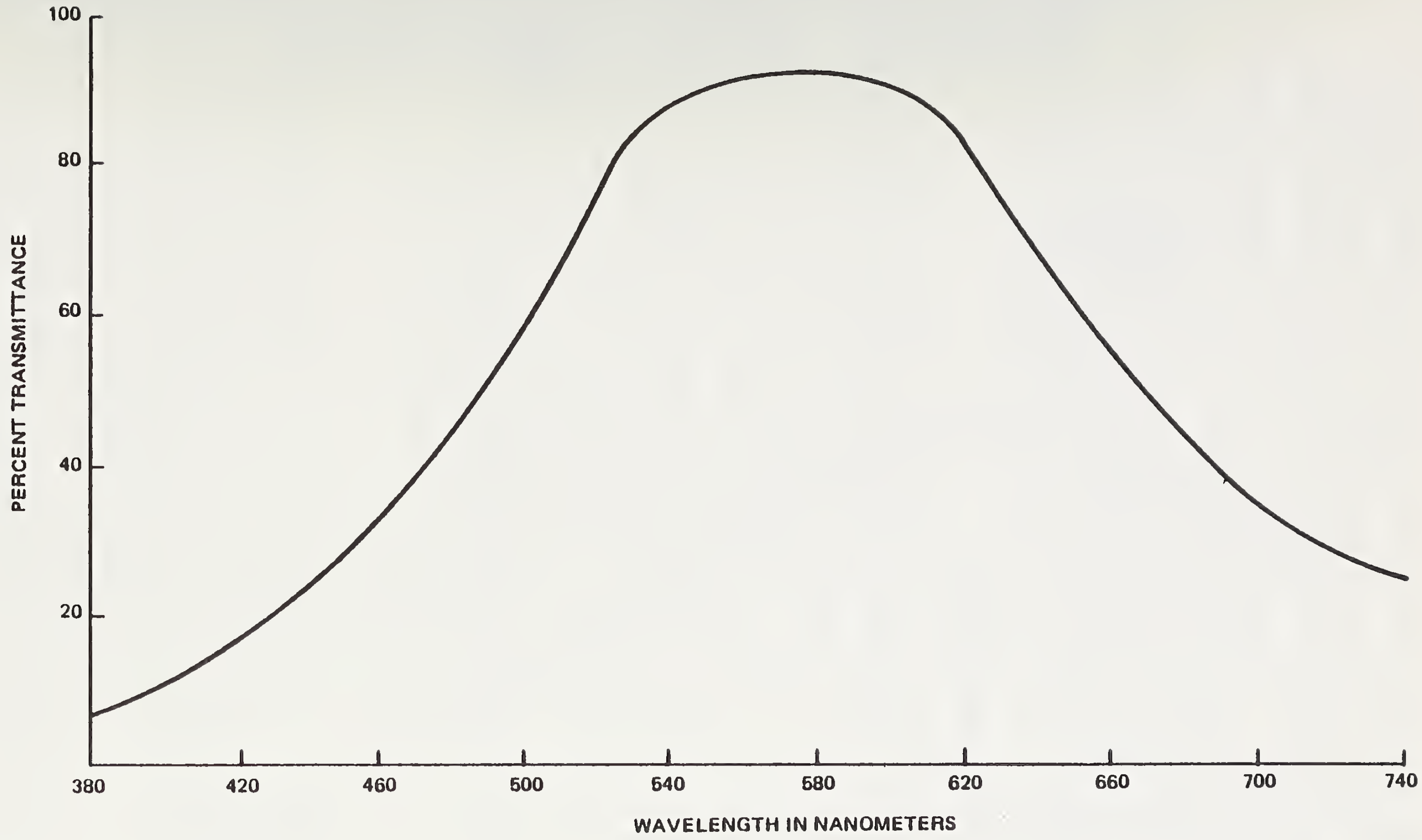

FIGURE B-3
FILTER (LENS) TRANSMITTANCE FUNCTION
(HYPOTHETICAL)

An "illuminated"* red car appears to be red because the paint is a mixture of pigments that partially absorb the shorter wavelengths while reflecting the longer wavelengths in the red region of the visible spectrum. In natural light, a red lens likewise appears red when it reflects natural or artifical light. When a white light source is placed behind the red lens or filter, the longer wavelengths are transmitted through the lens while the shorter wavelengths are greatly attenuated by the dyes in the lens. The light transmitted through the lens causes it to appear to the eye as a red light source (Ref. 5).

1.6 The Tungsten Lamp

Excluding the sun, the thermal radiator or light source with which we are most familiar is the tungsten filament used in common light bulbs. Tungsten filaments have been our basic artifical light source for about 65 years. Most tungsten filaments are operated at 2100°C to 2300°C in a vacuum bulb or in a bulb filled with an inert gas. Although most of the energy radiated by incandescent tungsten is in the invisible infrared region, the filament still radiates extremely well within the visible spectrum. Development of other types of light sources has given little or no indication that the tungsten filament will be altogether replaced as a light source. Considering versatility, cost and reliability of the tungsten filament light leads to the conclusion that it is likely to be the predominant artifical light producer for the foreseeable future.

Figure B-4 shows the relative wavelength distribution of energy radiated by a typical tungsten filament. Since the area under the curve indicates the quantity of energy emitted between given wavelengths, it can be seen that the total energy emitted in the red region is approximately four times greater than that in the blue region.

Based on the foregoing it may be concluded that lessor energy radiated by a tungsten filament will be transmitted through a medium blue lens while more radiated energy can be transmitted

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*See Glossary

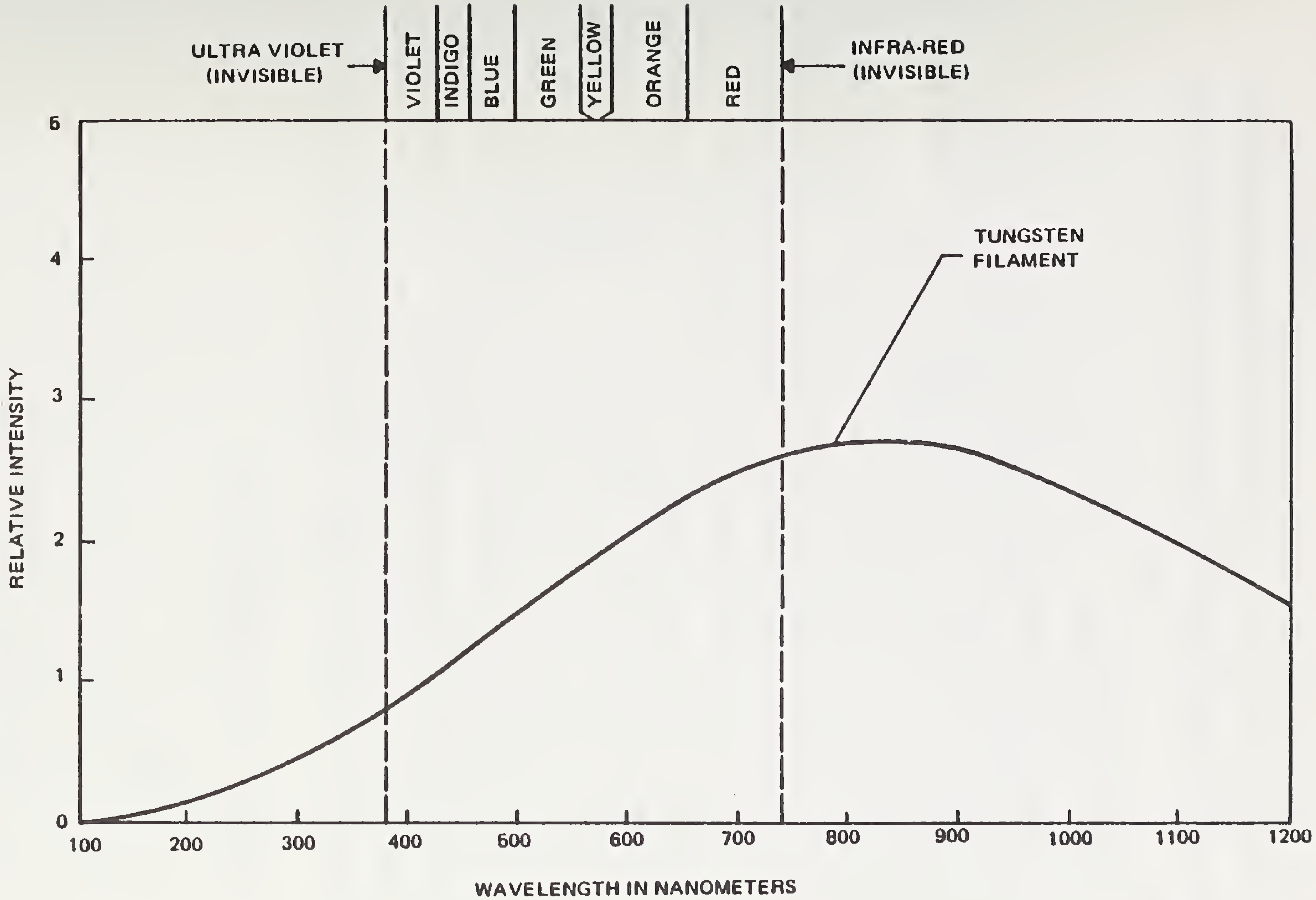

FIGURE B-4
SPECTRAL ENERGY DISTRIBUTION
OF A TYPICAL TUNGSTEN FILAMENT

through a medium red lens, which is the case in fact and the reason (neglecting eye sensitivity) that more powerful incandescent bulbs are required behind a blue lens than behind a red lens to achieve the same luminance level.

1.7 Xenon Flash Lamps

In recent years another thermal radiator, the xenon flash tube, has been employed as a flashing light source to increase conspicuity of aircraft, emergency vehicles, trains and some highway signals. Holmstrom (Ref. 6) reported many features of the xenon flash tube that indicate it may have great promise for improving conspicuity of active warning devices at grade crossings. Holmstrom's report discussed in detail the specifications, economics, availability and reliability. Also discussed were hardware configurations that could be used with the xenon tube as the light source for warning lights. Holmstrom calculated that xenon flash tubes produce 3.85 times as much apparent light per watt of electrical energy as do tungsten filaments.

Thermal radiation is emitted from a xenon flashtube when a very short, high voltage electrical pulse is discharged through ionized xenon gas confined in the sealed glass envelope. The energy discharged through the gas is electrical energy stored in a capacitor. This stored energy is expressed in Joules, which are the watt-seconds of energy.

Joules, J, are defined to be,

$$J = \frac{V^2 C}{2},$$

where,

C: Capacitance, in Farads

and,

V: Peak voltage across capacitor.

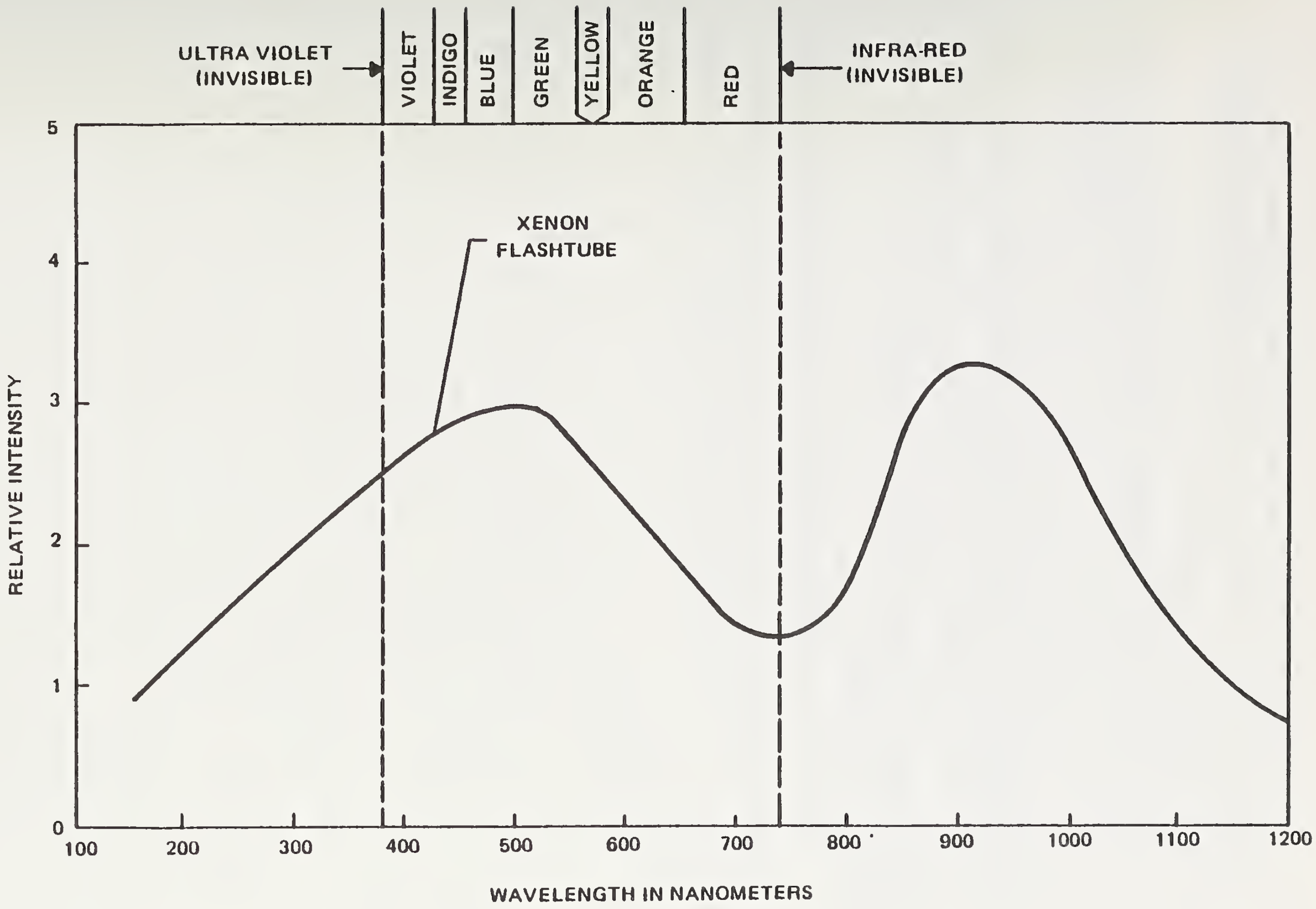

FIGURE B-5
SPECTRAL ENERGY DISTRIBUTION
OF A TYPICAL XENON FLASH TUBE

At the flash rate of two per second, a xenon flashtube rated at eight watt-seconds or joules per flash, consumes 16 watts of energy through the tube per second.

Figure B-5 shows specific measured spectral distribution of light emitted by a xenon tube. Some variations in spectral distribution occur through adjustment of the peak voltage across the flash tube. The higher the voltage, the more blue light and less red light per watt-second of energy used. However, at the lowest practical operating voltages, there is still more light radiated in the blue region than in the red region.

From the foregoing it may be concluded that the xenon flashtube is a more efficient source for radiating energy through a light blue lens than it is for radiating energy through a light red lens, which is the case in fact.

1.8 Conclusions

The concept of energy distribution of a light source was discussed for two examples (Tungsten filament lamps and xenon flash lamps) in sections 1.6 and 1.7. Transmittance of a lens or filter was described in section 1.5. Applying the transmittance, e.g., Figure B-3, to the spectral energy distribution of the light source, e.g., Figure B-4 or B-5, one obtains the spectrum of a given light source as attenuated by a given filter. Applying still another transmittance curve representing the attenuation of the spectrum between the filter and the eye will yield a second spectrum, i.e., that which reaches the eye and takes into account the light source, the filter and the transmission medium. The final stage in terms of what the eye sees is discussed in sections 1.3 and 1.4 and consists of applying the eye spectral sensitivity function which results in the observed spectral energy distribution and takes into account the <u>four</u> <u>major</u> factors contributing to color perception and brightness sensation. There are a number of other secondary factors (which may be primary factors dependent on the situation) which have not been discussed.

Several items which can be grasped, even with a rudimetry understanding of the foregoing, are as follows:

1) The amount of light energy transmitted by a given colored lens is highly dependent on the light source as well as the lens itself.

2) Reduced visibility conditions, e.g., fog, and what these conditions do to light energy is explainable via inspection of the transmittance curve of the medium itself.

3) There are many questions still to be answered particularly with respect to color and the meaning drivers attach to color under a wide variety of conditions.

REFERENCES

APPENDIX B

1. Judd, Dean B., Basic Correlates of the Visual Stimulus, "Handbook of Experimental Psychology," edited by S. S. Stevens, 1951.

2. Cole, B. L., Visual Aspects of Road Engineering, Proceedings, Australian Road Research Board, Vol. 6, Part 1, 1972, 102-148.

3. Visual Optics - "Military Standardization Handbook," MIL-HDBK-141 (1962).

4. Jenkins, FA; White, H.E.; Fundamentals of Optics, McGraw Hill Brook Co., Inc., New York; Third Edition, 1957.

5. Filters - "Kodak Reference Hnadbook," Eastman Kodak Co. (1947).

6. Holmstrom, F. Ross, Presented to AAR Meeting, New Orleans, Louisiana, 1975.

APPENDIX C

1.0 STATISTICAL PROCEDURES

This Appendix contains a discussion of the contingency table analysis as applied to test subject response scoring in the indoor laboratory tests.

Three to six primary devices were chosen to compare relative conspicuity each test day. Following several days of pilot testing, each test subject was asked to identify only a single target, which either initially caught or persistently held his attention, as discussed in Appendix D. Each display presented to each subject was scored as a simple "Yes" or "No," i.e., it was noted on the test subject's form or it was not noted on that form. Thus, when a specific target appeared in ten separate displays, presented to nine subjects, that target had 90 opportunities to be chosen during the test session. This total number of opportunities to be chosen during the test session shall hereafter be referred to as "sample size."*

This type of scoring was chosen since it provides conclusions with statistical basis. The statistical test compared the frequency of "Yes" and "No" answers for two primary targets. This test is called a 2 x 2 Contingency Table Analysis. The 2 x 2 means 2 primary targets x 2 responses (yes or no) per primary target. The test was based upon the hypothesis that the two targets have equal conspicuity. Equal conspicuity means the relative frequency of yes and no answers are approximately the same for both targets. If the relative frequency of yes, no answers differ by too much, then the hypothesis of equal conspicuity is rejected. When equality is rejected, the primary target, having higher relative frequency of yes responses is said to be more conspicuous. In all cases, the primary targets were analyzed in pairs. The concept of relative conspicuity refers to the results of such

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*See Glossary

pairwise comparisons. A large difference can be equated to a quantity termed statistical significance. Statistical significance is usually denoted by the quantity α. In layman's language, if one rejects the hypothesis of equal conspicuity when:

$\alpha = .1$, it's a good bet;

$\alpha = .001$, it's just next to a sure thing.

The method of measuring how the relative yes/no frequencies differ between two primary targets is through use of a statistical quantity. This statistical quantity is called the Chi-square (χ^2) statistic. The formula for determining the value of χ^2 is given in suceeding sections. It is possible to calculate a theoretical value of α corresponding to the sample value of χ^2. In summary, when:

$\chi^2 = 2.71$ then $\alpha = .1$

$\chi^2 = 10.96$ then $\alpha = .001$

If for a given pairwise comparison, $\chi^2 < 2.71$, then the conclusion was that there was insufficient statistical evidence to conclude that the primary target having higher relative frequency of yes responses was the more conspicuous. If the value of $\chi^2 > 2.71$, then there is sufficient statistical evidence to conclude that the primary target with the higher relative frequency of yes responses is the more conspicuous. The degree of assurance one has in making this conclusion, is found by calculating the α which corresponds to the given value of $\chi^2 > 2.71$. The smaller the α, the more assurance one has in concluding one primary target is more conspicuous than the other. Therefore, for all χ^2 values greater than 2.71, the corresponding α was calculated. The exception was, if $\chi^2 > 10.96$, whereby the corresponding α was less than .001. It was the project staff's opinion, that if $\alpha \leq .001$, the evidence for rejection of equal conspicuity was overwhelming and hence the value of $\alpha < .001$ corresponding to a specific $\chi^2 > 10.96$ carried little meaning.

A more formal discussion of the χ^2 test follows.

1.1 Contingency Table Analysis

For each test day, the number of primary targets ranged from three to six while the number of decoys might have been as high as 12 combinations of lights and signs. Following accumulation of the test subject observations the primary target scores were broken down into an r by 2 matrix. The number of rows, r, conformed to the number of primary targets (3, 4, 5, or 6) while the two columns of the matrix contained the number of times the respective primary target was noted and the number of times it was not noted. Table 1 is a typical example for the case of r = 4 primary targets. The quantities b, d, f, and h are the number of times the targets A, B, C, and D were not seen, respectively.

1.2 Chi-Square Test

The Chi-Square (χ^2) test was used to determine the significance of differences between independent groups and is discussed by Siegel (Ref. 1, page 104ff). The χ^2 statistic is given by:

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{k} \frac{(O_{ij} - E_{ij})}{E_{ij}} \qquad \text{(C-1)}$$

where

r is the number of groups (primary devices)

k is the number of possible categories (classifications or outcomes) for each group

O_{ij} is the observed frequency of the jth category for the ith group

and E_{ij} is the expected frequency of the jth category of the ith group under the null hypothesis (H_o).

The information of most importance was the pairwise comparison of primary targets for each test period. In this case the number of groups (r) in each test is two, while the number of classifications (k) is also two (yes, it was noted by a test subject, or no, it was not noted by the test subject). The number of such pairwise comparisons of primary targets is given by:

$$\binom{M}{2} = \frac{M!}{(M-2)!2!} \qquad \text{(C-2)}$$

where M is the number of primary targets. For $M = 4, \binom{M}{2} = 6$; for $M = 6, \binom{M}{2} = 15$. These pairwise comparisons reduce to $\binom{M}{2}$ significance tests of primary targets, where each test is described by a 2 x 2 contingency table. The 2 x 2 table is best covered by Mode (Ref. 2, page 210ff) where χ^2 of equation 1 is given by:

$$\chi^2 = \frac{N(ad-bc)^2}{r_1 r_2 k_1 k_2} \qquad \text{(C-3)}$$

where N, a, d, b, c, r, r_2, k_1, k_2 are described similarly in a 2 x 2 version of the 4 x 2 Contingency Table shown in Table C-1. A continuity correction due to Yates (1934) results in a modified value of χ^2 (corrected) given by:

$$\chi^2 \text{ (corrected)} = \frac{N\left\{(ad-bc) - \frac{N}{2}\right\}^2}{r_1 r_2 k_1 k_2} \qquad \text{(C-4)}$$

The value of χ^2 (corrected) is approximately distributed as the chi-square variate (x) with one degree of freedom and density function

$$f(x) = \frac{e^{-x/2}}{\sqrt{2\pi x}} \qquad x \geq 0 \qquad \text{(C-5)}$$

TABLE C-1
CONTINGENCY TABLE (4 x 2)

	Number of Times Seen	Number of Times Not Seen	Marginal Total
TARGET A	a	b	$r_1 = a + b$
TARGET B	c	d	$r_2 = c + d$
TARGET C	e	f	$r_3 = e + f$
TARGET D	g	h	$r_4 = g + h$
MARGINAL TOTALS	$k_1 = a + c + e + g$	$k_2 = b + d + f + h$	$N = r_1 + r_2 + r_3 + r_4$ $= k_1 + k_2$

The cumulative probability function P(x) is given by

$$P(x) = \int_{o}^{x} f(t)\, dt$$

$$= 2xf(x) \left\{ 1 + \sum_{k=1}^{\infty} \frac{x^k}{(3)(5)(7)\cdots(1+2k)} \right\} \qquad \text{(C-6)}$$

1.3 Null Hypotheses

The <u>null hypothesis</u> for each pairwise primary target comparison was that there was <u>no relative conspicuity difference</u> (frequency of yes and no) between the two targets.

For all values of χ^2, equation C-4, greater than 2.71 (α less than .1) the corresponding $\alpha = 1 - P(\chi^2)$ was calculated using equations C-5 and C-6. If, however, $\chi^2 > 10.96$ ($\alpha < .001$) then corresponding α values were so small that the calculation was not made.

A Texas Instruments, SR-52 programmable hand calculator was used for calculation of χ^2 values, equation C-4, as well as $1 - P(\chi^2)$, equation C-6 for those instances where $2.71 < \chi^2 < 10.96$.

REFERENCES

APPENDIX C

1. Siegel, S., Non-Parametric Statistics, McGraw-Hill, 1956.
2. Mode, E. B., Elements of Statistics, Prentice Hall, 3rd Edition, 1961.

APPENDIX D

1.0 INDOOR LABORATORY TESTS

The following sections present a discussion as well as a table summary presentation of raw data results.

The typical 2 x 2 Contingency Table defined in Appendix C is shown below.

Comparing Targets	Yes	No
Target A	a	b
Target B	c	d

2 x 2 Contingency Table

For presentation of summary data, the form of the 2 x 2 Contingency Table above was translated to that shown below.

Comparing Targets	2 x 2 Contingency Table A Yes	A No	B Yes	B No	χ^2	Significance (α)
Target A & Target B	a	b	c	d	(example) 2.70	(example) 0.10

2 x 2 Contingency Table (Translated)

The above form was designed to present all the applicable data concerning one pairwise comparison on a single line of type.

2.0 COLOR TESTS

When developing the initial work plan for the laboratory experiment, time and financial restraints dictated limited comparison of pairs of flashing lights to four color combinations. For primary targets, a pair of reds at the pale end of the hue region were selected, as approved by the American Railroad Association. Second choice was a pair of blues of the hue that has been a popular choice for use on police and other emergency vehicles in the past five years. The third choice was a combination of one red and one blue of the same hues as was used for the red-red and the blue-blue light pairs. It was felt this combination might take advantage of daylight sensitivity to red and nighttime sensitivity to blue to produce the overall most conspicuous pair. Pudinski (ref. 1) concluded that blue lights had definite advantages for use on police cars. He further concluded that combinations of red and blue lights may offer the most improved conspicuity over the traditional red and yellow lights. The fourth choice for testing was an orange-orange pair of a hue similar to the deep orange now used on roadway construction. For a number of years some highway, railroad and human factors researchers have felt there may be improvement in the conspicuity of railroad flashing pairs by lightening the traditional dark hues and obtaining greater energy transmission (luminance) through the lens. It seemed reasonable to investigate an area of the color spectrum not too far from the pale reds, and the orange-orange pair fit this specification. The eye is also more sensitive to the orange wavelengths than the red wavelengths and there might be some area for possible tradeoffs.

There were actually four color tests conducted. The data from the first two test groups were discarded when the project staff concluded that these data were contaminated by a strong position bias as discussed in Section 4.1.4. As a result of these two initial tests, the project team was very careful to position-balance the primary devices during conduct of succeeding tests.

The color tests reported in the two succeeding sections provided interesting results within themselves, and also between the two tests. The two tests differed by a factor of 3 to 1 (4.5 seconds vs. 1.5 seconds) in the time duration of test subject exposure to displays.

2.1 Color Test Group I

Primary Targets tested were:

Primary Target #1 : 8"[*]Diameter Red-Red alternating flashing pair of lights

Primary Target #2 : 8"[*]Diameter Red-Blue alternating flashing pair of lights

Primary Target #3 : 8"[*]Diameter Blue-Blue alternating flashing pair of lights

Primary Target #4 : 8"[*]Diameter Orange-Orange alternating flashing pair of lights

Each display was presented to the test subjects for 4.5 seconds. Test subjects were instructed to select the target that held their attention the greater portion of the 4.5 seconds. All primary devices flashed at 55/min. The luminance of all primary devices was 550 fL daylight and 275 fL at night.

The data obtained form Group I clearly indicated that the orange-orange had significantly less attention getting property than reds or blues in clear daylight and in clear darkness. However, there was almost no difference among the colors in the fog, but a considerable increase in selection of the orange-orange pair of lights. Since all lights were displayed at the same luminance, these results suggest that the wavelengths near the center of the visible spectrum (yellow) are more formidable competition to the reds and the blues in daylight fog

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[*] 8 inches = 20.3 cm

than in clear weather. This result may well have human factors explanation but no physical explanation relative to transmittance of energy through a fog medium.

As shown in Tables D-1 and D-2, there was no significant differences in target values of red-red, red-blue, and blue-blue in daylight tests. However, as one might have predicted from discussions of the Purkinje Shift in Appendix B, there was a significant preference for the blue-blue over the red-red in darkness. Nighttime results shown on Table D-1 suggest that there was an established rank order of blue-blue, blue-red, and red-red, as one might expect. The fact that sensitivity to blue increased at night, raised the confidence level in the psychology of the test design as well as the credibility of the group of test subjects.

All primary targets were selected at the highest frequency in the fog. This was true with few exceptions throughout the laboratory tests. The obvious explanation was that the sign decoys were never clearly visible to the test subjects in the fog. There were, therefore, fewer clearly visible targets to choose from and hence all visible targets were chosen more frequently.

2.2 Color Test Group II

Primary Target #1 = 8"[*] diameter red-red alternating flashing pair
Primary Target #2 = 8"[*] " red-blue " " "
Primary Target #3 = 8"[*] " blue-blue " " "

The test conditions were;

1) All targets flashed at 55/minute,
2) All targets displayed at lumince of 550 fL,
3) Test subjects were asked to choose the target that got their attention first,
4) The display period was $1\frac{1}{2}$ seconds long.

[*] 8 inches = 20.3 cm

Test results for this group of subjects is shown in Tables D-3 and D-4. This orange-orange pair was eliminated as one of the primary targets, for this second group. Comparison of the relative frequency of test subject choices of primary targets greatly decreased for the second test, see Tables D-1 and D-3. This decrease was due to use of a different set, much more competitive, of decoy targets for the second test group.

The color data from this group of subjects once again indicates no significant difference in conspicuity among these three color combinations. There was slight indication of increased sensitivity to blue at night.

TABLE D-1
Color Test Group I - Test Scores

#	Primary Device	Daylight-Clear			Daylight-Fog			Nighttime-Clear		
		Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
1	8" Red-Red	108	53	49	54	28	52	108	42	39
2	8" Red-Blue	108	53	49	54	36	67	108	53	49
3	8" Blue-Blue	108	56	52	54	30	56	108	61	56
4	8" Orange-Or.	108	25	23	54	37	69	108	33	31

TABLE D-2
Color Test Group I - Statistical Analysis

When Pairwise Comparing Color Combinations	2x2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level Shown
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
Blue-Blue & Red-Red	56	52	53	55	0.074	-
Blue-Blue & Red-Blue	56	52	53	55	0.074	-
Blue-Blue & Orange-Orange	56	52	25	83	17.778	< 0.001
Red-Red & Red-Blue	53	55	53	55	0.019	-
Red-Red & Orange-Orange	53	55	25	83	14.629	< 0.001
Red-Blue & Orange-Orange	53	55	25	83	14.629	< 0.001
In Daylight - 450 ft. Visibility Fog						
Orange-Orange & Red-Blue	37	17	36	18	0.000	-
Orange-Orange & Blue-Blue	37	17	30	24	1.415	-
Orange-Orange & Red-Red	37	17	28	26	2.473	-
Red-Blue & Blue-Blue	36	18	30	24	0.974	-
Red-Blue & Red-Red	36	18	28	26	1.879	-
Blue-Blue & Red-Red	30	24	28	26	0.037	-
In Darkness - Clear Weather - Rural Simulation						
Blue-Blue & Red-Blue	61	47	53	55	0.910	-
Blue-Blue & Red-Red	61	47	42	66	6.013	0.014
Blue-Blue & Orange-Orange	61	47	33	75	13.731	< 0.001
Red-Blue & Red-Red	53	55	42	66	1.879	-
Red-Blue & Orange-Orange	53	55	33	75	6.975	0.008
Red-Red & Orange-Orange	42	66	33	75	1.307	-

1 inch = 2.5 cm
1 foot = .3 meters

TABLE D-3
Color Test Group II - Test Scores

#	Target	Daylight-Clear			Daylight-Fog			Nighttime-Clear		
		Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
1	Red-Red	176	53	30	198	66	33	198	64	32
2	Red-Blue	176	50	28	198	60	30	198	70	35
3	Blue-Blue	176	45	26	198	58	29	198	57	29

TABLE D-4
Color Test Group II - Statistical Analysis

When Pairwise Comparing Color Combinations	2x2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
Red-Red & Red-Blue	53	123	50	126	0.055	-
Red-Red & Blue-Blue	53	123	45	131	0.693	-
Red-Blue & Blue-Blue	50	126	45	131	0.231	-
In Daylight - 450 ft. Visibility Fog						
Red-Red & Red-Blue	66	132	60	138	0.291	-
Red-Red & Blue-Blue	66	132	58	140	0.575	-
Red-Blue & Blue-Blue	60	138	58	140	0.012	-
In Darkness - Clear Weather - Rural Simulation						
Red-Red & Red-Blue	64	134	70	128	0.282	-
Red-Red & Blue-Blue	64	134	57	141	0.428	-
Red-Blue & Blue-Blue	70	128	57	141	1.669	-

1 foot = .3 meters

3.0 FLASHRATE TESTS

Flashrate tests were initially conducted with incandescent bulbs whose filaments were found to lose about 60 milliseconds of peak radiation time with each flash cycle, with loss time defined as "heating time to 90 percent maximum light minus cooling time to 10 percent maximum light. It is possible, almost, to eliminate the peak radiation time loss with most tungsten filaments at moderate flashrates. Filaments of the size used for warning light applications radiate very little light until they reach about 1500°C. When one holds voltage across the filament during the off phase of each duty cycle, the filament requires less heating time and longer cooling time. At the optimum holding voltage, there will be no apparent peak radiation time losses. There was not sufficient time and resources to be quite so sophisticated during the flashrates tests. Therefore, the total peak radiation time per minute may have had some important interaction influences upon the tests of five specific flashrates, i.e., the lights may have dimmed with higher flash rates. Since all tests were performed with power on 50 percent of the time, the relative light radiated at the five flashrates can be compared as shown in Table D-5.

TABLE D-5
PEAK RADIATION TIME VS. FLASH RATE

Flashrate Per Minute	Peak Radiation Time		
	Peak Time Per Minute	Per Flash	% On
40	27.6 seconds	.690 sec.	46.0
55	26.7 seconds	.485 sec.	44.5
70	25.8 seconds	.369 sec.	43.0
90	24.6 seconds	.273 sec.	41.0
120	22.8 seconds	.190 sec.	38.0

Flashrates of about 55/min. have traditionally been used for flashing, traffic light devices. When developing testing techniques and designs for studying flashrates, it was decided that the objective should be to determine whether other flashrates offer improved conspicuity over the 55 cycles/min. value. Arbitrarily selected rates of 40/min., 70/min., 90/min., and 120/min. were compared with the 55/min. standard.

It was concluded that flashrates could best be studied when comparing them three at a time. For the first day's tests, 40/min., 70/min., and 120/min. flashrates were selected with plans to choose the day's winner** and add other flashrates for the second day's testing.

3.1 Flashrate Test Group I

The first group of subjects used to test flashrates were shown primary displays of red-red, orange-orange, and amber-amber. The test conditions were as follows:

1) Each signal head diameter was 8-inches.*
2) All targets were set to 550fL in daylight and 275fL at night.
3) Each colored light pair appeared an equal number of times at each flashrate.
4) Each display was presented for 4-1/2 seconds at 420 feet.*
5) Test subjects were asked to note the target that captured their attention for the longest portion of the display period.

The results of the first day of flashrate testing are shown in Tables D-6 and D-7.

* 8 inches = 20.3 cm
420 feet = 128.1 meters

**See Glossary

TABLE D-6

Flashrate Test Scores (Group I)

Device	Daylight-Clear			Daylight-Fog			Nighttime-Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
@ 120/min.	225	57	25	243	43	18	243	46	19
@ 70/min.	243	90	37	243	64	26	234	76	32
@ 40/min.	243	56	23	225	38	17	234	37	16

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TABLE D-7

Flashrate Analysis (Group I)

When Pairwise Comparing Flashrates Summing Results from Red-Red, Orange-Orange & Amber-Amber	2x2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a Yes	b No	c Yes	d No		
In Daylight - Clear Weather - Rural Simulation						
@ 70/min. & @ 120/min.	90	153	57	168	6.894	0.009
@ 70/min. & @ 40/min.	90	153	56	187	12.662	0.001
@ 120/min. & @ 40/min.	57	168	56	187	0.221	-
In Daylight - 450 ft. Visibility Fog						
@ 70/min. & @ 120/min.	64	179	43	200	4.794	0.029
@ 70/min. & @ 40/min.	64	179	38	187	5.577	0.018
@ 120/min. & @ 40/min.	43	200	38	187	0.012	-
In Darkness - Clear Weather - Rural Simulation						
@ 70/min. & @ 120/min.	76	158	46	197	10.795	0.001
@ 70/min. & @ 40/min.	76	158	37	197	16.846	<0.001
@ 120/min. & @ 40/min.	46	197	37	197	0.604	-

1 foot = .3 meters

The variation in sample size shown in Tables D-6 and D-7 was due to equipment failures during the course of the test that made deletion of some displays advisable. A careful look at the deleted displays indicated that their omission would have no material effect on the overall results.

Cole (ref. 2), Geranthewohl (ref. 3) and many other researchers have concluded that flashing lights are more conspicuous than steady burning. Although most of their investigations and conclusions concerned single flashing lights at lower luminance levels, it was expected that most of their flashrate conclusions would apply to pairs of flashing lights at higher luminance levels. It was fully expected that increasing conspicuity would be found as flashrates were increased from 60-240 cycles per minutes as Geranthewohl reported. With display presentations only 4-1/2 seconds long, one might expect the faster rates to be more conspicuous since "more action" is concentrated in the short and fixed time period. However, the flashrate Test Group I clearly demonstrated a strong preference for the 70/min. flashrate over the 40/min. or the 120/min. rates.

3.2 Flashrate Test Group II

Since the flashrate, 70/min., was a clear favorite the first day, this rate was compared with 55/min. and 90/min. in the second day's tests. Test conditions were as follows:

1) Primary targets were a red-red and a red-blue flashing pairs.

2) Each primary target was presented an equal number of times at each of the three flashrates.

3) Each signal head diameter was 8 inches.

4) All targets were set to 550fL in daylight and 275fL at night.

5) Each display consisted of six targets.

Results are shown in Tables D-8 and D-9 and reveal no statistical significance in pairwise comparison of the three flashrates.

TABLE D-8

Flashrate Test Scores (Group I)

Target	Daylight - Clear			Daylight - Fog			Nighttime - Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
@55/min.	192	63	33	192	52	27	192	60	31
@70/min.	192	54	28	192	61	32	192	59	31
@90/min.	192	52	27	192	62	32	192	68	35

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TABLE D-9

Flashrate Test Group II - Statistical Analysis

When Pairwise Comparing Flashrates Summing Results from the Red-Red & Red-Blue Devices	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
@ 55/min. & @ 70/min.	63	129	54	138	0.737	-
@ 55/min. & @ 90/Min.	63	129	52	140	1.241	-
@ 70/min. & @ 90/min.	54	138	52	140	0.013	-
In Daylight - 450 ft. Visibility Fog						
@ 90/min. & @ 70/min.	62	130	61	131	0.000	-
@ 90/min. & @ 55/min.	62	130	52	140	1.011	-
@ 70/min. & @ 55/min.	61	131	52	140	0.803	-
In Darkness - Clear Weather - Rural Simulation						
@ 90/min. & @ 55/min.	68	124	60	132	0.574	-
@ 90/min. & @ 70/min.	68	124	59	133	0.756	-
@ 55/min. & @ 70/min.	60	132	59	133	0.000	-

1 foot = .3 meters

3.3 Flashrate Test Group III

A third group of subjects gave a direct comparison of flashrates of 55/min. and 90/min. Although the test session was primarily interested in comparing luminance, the test was designed using two flashrates with balanced competition. Test conditions were as follows:

1) Primary targets were 8 inch* diameter red-red and red-blue pairs.
2) All primary targets were displayed at 55/min. and 90/min.
3) All primary targets were displayed at 275fL, 550fL, and 1100fL luminance.
4) Each color, luminance level, and decoy combination was displayed an equal number of times with each flashrate.
5) Each display was presented for 4-1/2 seconds.
6) Test subjects were asked to choose the target that held their attention the longest portion of the display period.

Results are shown in Tables D-10 and D-11. Test subjects found no difference in conspicuity between flashrates of 55/min. and 90/min., confirming the findings from Test Group II.

Since the experimental design for Flashrate Test Group III used a balanced presentation of red-red and red-blue primary targets, it is possible to once again investigate color comparison. Summing across flashrates and intensity levels, a red-red and red-blue color comparison can be made with the Group III data. This information is shown in Table D-12. As seen from Table D-12, increased nighttime sensitivity to blue was quite obvious within this group of subjects. Furthermore, the daytime fog results are completely consistent with theory and prior experimentation relative to fog particle attenuation of blue (shorter) wavelengths.

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* 8 inches = 20.3 cm

TABLE D-10

Flashrate Test Scores (Group III)

Target	Daylight - Clear			Daylight - Fog			Nighttime - Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
55/min.	162	52	32	162	71	44	162	86	53
90/min.	162	45	28	162	63	39	162	89	55

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TABLE D-11

Flashrate Test Group III - Statistical Analysis

When Pairwise Comparing Flashrates Summing Results of Red-Red and Red-Blue Pairs at 3 Latensity Levels	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
@ 55/min. & @ 90/min.	52	110	45	117	0.530	-
In Daylight - 450 ft. Visibility Fog						
@ 55/min. & @ 90/min.	71	91	63	99	0.624	-
In Darkness - Clear Weather - Rural Simulation						
@ 55/min. & @ 90/min.	86	76	89	73	0.050	-

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TABLE D-12

Flashrate Test Group III - Color Comparison

Target	Daylight - Clear			Daylight - Fog			Nighttime - Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
Red-Red	162	50	31	162	74	46	162	79	49
Red-Blue	162	47	29	162	60	37	162	96	59

1 foot = .3 meters

4.0 LUMINANCE TESTS

Luminance, sometimes called photometric brightness, is defined as "luminus flux," per solid angle unit and per unit of surface area subtended by that angle flowing from a given point in a given direction. During the course of the study, luminance was measured in footlamberts (fL) as previously discussed. A footlambert is $1/\pi$ candella per square foot.*

The photometer used for all laboratory light measurements had nearly the same sensitivity to wavelengths in the visual spectrum as the human eye, shown on the photopic curve, Appendix C. Therefore, the relative "brightness"** of two lights of different colors should be the same to a human eye as to the photometer.

The eye is, however, quite logarithmic in its ability to discriminate brightness differences, particularity in low contrast, bright daylight conditions. As the contrast increases, the eye becomes more sensitive to brightness difference until scotopic vision is reached, provided what is being discriminated between is near threshold levels. Fixed luminance light sources do not fit the foregoing definition and as ambient light decreases to darkness, in lack of other background competition, the luminance levels vastly exceed threshold detection and hence may likely cause saturation of the eye and hence a loss of brightness discrimination.

4.1 Luminance Test Group I

The test conditions were:

1) All primary targets were 8"* heads.
2) All primary targets were either red-red or red-blue.
3) All primary targets were presented at 55/min. or 90 min.

* 1 square foot = .09 square meters
8 inches= 20.3 cm

**See Glossary

4) Each color, flashrate, and target position combination was presented once at each luminance level.

5) Each display was presented for 1-1/2 seconds.

6) Test subjects were asked to note the target that got their attention first.

Test subject scores are shown in Tables D-13 and D-14 and reveal the range of luminance and the background contrast being tested.

1) Quadrupling luminance produced a significant change in conspicuity in clear weather, where doubling luminance may or may not produce a significant change, dependent on the levels compared.

2) Quadrupling luminance has little or no effect on conspicuity at night.

The fog results are explainable at the luminance levels tested, i. e., the lights were near threshold and about to disappear. The nighttime results reveal saturation at high contrast levels. The daytime, clear weather scores reveal something interacting with background contrast and the respective luminance levels tested, presently beyond explanation of the researchers.

Reexamination of the red and blue preferences of this subject group again showed a significant increase in sensitivity to blue at night.

4.2 Luminance Test Group II

A second group of test subjects similarly compared differences in luminance. The test conditions were:

1) All primary targets were red-red.

2) All targets flashed at 55/min.

TABLE D-13
Luminance Group I - Test Scores

Target	Daylight - Clear			Daylight - Fog			Nighttime - Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
@ 275 fL	108	27	25	108	16	15	108	63	58
@ 550 fL	108	28	26	108	38	35	108	52	48
@ 1100 fL	108	42	39	108	81	75	108	60	56

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TABLE D-14
Luminance Group I - Statistical Analysis

When Pairwise Comparing Radiant Intensity Summing Results from Red-Red and Red-Blue, Both @ 55/min. & @ 90/min.	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		

In Daylight - Clear Weather - Rural Simulation

@ 1100 fL & @ 550 fL	42	66	28	80	3.572	0.059
@ 1100 fL & @ 275 fL	42	66	27	81	4.174	0.041
@ 550 fL & @ 275 fL	28	80	27	81	0.000	

In Daylight - 450 ft. Visibility Fog

@ 1100 fL & @ 550 fL	81	27	38	70	33.009	<0.001
@ 1100 fL & @ 275 fL	81	27	16	92	76.647	<0.001
@ 550 fL & @ 275 fL	38	70	16	92	10.889	<0.001

In Darkness - Clear Weather - Rural Simulation

@ 275 fL & @ 1100 fL	63	45	60	48	0.076	
@ 275 fL & @ 550 fL	63	45	52	56	1.860	
@ 1100 fL & @ 550 fL	60	48	52	56	0.909	

1 foot = .3 meters

3) One pair was 8"* heads and one pair was 12"* heads.

4) 8"* heads were displayed at 620fL and at 1240fL.

5) 12"* heads were displayed at 275fL and at 550fL.

6) Each display was presented for 3-1/2 seconds.

7) Test subjects were asked to note the target that held their attention the longest.

Results are presented in Tables D-15 and D-16. Although not identical with the first test group, the pattern of responses are reasonably consistent with luminance Test Group I despite the introduction of 12"* heads and a change in the luminance levels tested.

4.3 Luminance Test Group III

Test conditions were as follows:

- All primary targets were red-blue.
- All targets flashed at 55/min.
- One pair was 8"* heads and one pair was 12"* heads.
- 8"* heads were displayed at 275fL and at 550fL.
- 12"* heads were displayed at 275fL.
- Each display was presented for 4-1/2 seconds. Test subjects were asked to note the target that held their attention the longest.

The results of the Group III tests are shown in Tables D-17 and D-18. Results are very consistent with prior discussion.

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* 8 inches = 20.3 cm
12 inches = 30.5 cm

TABLE D-15

Luminance Group II - Test Scores

#	Target	Daylight - Clear			Daylight - Fog			Nighttime - Clear		
		Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
1	8'' Red-Red @ 620 fL	81	22	27	81	21	26	81	25	31
2	8'' Red-Red @ 1240 fL	81	31	38	81	42	52	81	29	36
3	12'' Red-Red @ 275 fL	81	33	41	81	40	49	81	39	48
4	12'' Red-Red @ 550 fL	81	36	44	81	50	62	81	47	58

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TABLE D-16

Luminance Group II - Statistical Analysis

In Daylight - Clear Weather - Rural Simulation

When Pairwise Comparing Luminance of Red-Reds	2 x 2 Contingency Table a Yes	b No	c Yes	d No	χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at level
8'' @ 620 fL & 8'' @ 1240 fL	22	59	31	50	1.795	-
12'' @ 275 fL & 12'' @ 550 fL	33	48	36	45	0.101	-

In Daylight - 450 ft. Visibility Fog

When Pairwise Comparing Luminance of Red-Reds	2 x 2 Contingency Table a Yes	b No	c Yes	d No	χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at level
8'' @ 620 fL & 8'' @ 1240 fL	21	60	42	39	10.390	0.001
12'' @ 275 fL & 12'' @ 550 fL	40	41	50	31	2.025	-

In Darkness - Clear Weather - Rural Simulation

When Pairwise Comparing Luminance of Red-Reds	2 x 2 Contingency Table a Yes	b No	c Yes	d No	χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at level
8'' @ 620 fL & 8'' @ 1240 fL	25	56	29	52	0.250	-
12'' @ 275 fL & 12'' @ 550 fL	39	42	47	34	1.215	-

1 inch = 2.5 cm
1 foot = .3 meters

TABLE D-17

Luminance Group III - Test Scores

Target	Daylight - Clear			Daylight - Fog			Nighttime- Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
8" @ 275 fL	63	32	51	63	26	41	63	35	56
8" @ 550 fL	63	38	60	63	37	59	63	29	46
12" @ 275 fL	63	42	67	63	47	75	63	37	59
12" @ 550 fL	63	47	75	63	58	92	63	41	65

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TABLE D-18

Luminance Group III - Statistical Analysis

When Pairwise Comparing Luminance of Red-Blues	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		

In Daylight - Clear Weather - Rural Simulation

8" @ 275 fL & 8" @ 550 fL	32	31	38	25	0.804	-
12" @ 275 fL & 12" @ 550 fL	42	21	47	16	0.612	-

In Daylight - 450 ft. Visibility Fog

8" @ 275 fL & 8" @ 550 fL	26	37	37	26	3.175	0.075
12" @ 275 fL & 12" @ 550 fL	47	16	58	5	5.714	0.017

In Darkness - Clear Weather - Rural Simulation

8" @ 275 fL & 8" @ 550 fL	35	28	29	34	0.794	-
12" @ 275 fL & 12" @ 550 fL	37	26	41	22	0.303	-

1 inch = 2.5 cm
1 foot = .3 meters

5.0 SIZE/LUMINANCE TESTS

As previously discussed, all measurements of luminance were in foot Lamberts. The most interesting comparison of 8"* heads and 12"* heads occurred when luminance was adjusted so that the same total quantity of light was emitted by both 8"* and 12"* heads, as measured at a location directly in front of both heads. This is roughly equivalent to using the same amount of power (light bulb wattage) in each head.

The 12"* heads were not exactly 12"* diameter. The 8"* heads were not exactly 8"* diameter. The 12"* heads exposed approximately 2.255 times the luminated area exposed by the 8"* heads. Therefore, the 8"* heads were set at 2.255 times the luminance of the 12"* heads.

Without considering what comprised the decoy competition for these tests one might likely jump to a number of conclusions. The decoy set, against which the primary targets were tested, consisted of both 8"* and 12"* heads and each primary target was balanced against the same decoy arrangement. Since it is no revelation that increased target size is a way to overcome opposition--it must be realized that any direct conclusion must consider that the 12"* head was *larger* or of the *same size* as the decoys, while the 8"* head was either *smaller* or *no larger* than the decoy set. Considering, therefore, the decoy set as fixed competition, to both the 12"* and 8"* primary targets, the discussion of results will center around how size/luminance might be used to overcome competition. The scoring results are presented for both test groups and the results discussed.

5.1 Size/Luminance Test Group I Results

The results of Size Group I scores are shown in Tables D-19 and D-20. Test conditions were as follows:

1) All primary targets were red-red.
2) All targets flashed at 55/min.
3) One pair was 8"* heads and one pair was 12"* heads.

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* 8 inches = 20.3 cm
12 inches = 30.5 cm

TABLE D-19
Size Group I - Test Scores

#	Target	Daylight - Clear			Daylight - Fog			Nighttime - Clear		
		Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
1	8" Red-Red @ 620 fL	81	22	27	81	21	26	81	25	31
2	8" Red-Red @ 1240 fL	81	31	38	81	42	52	81	29	36
3	12" Red-Red @ 275 fL	81	33	41	81	40	49	81	39	48
4	12" Red-Red @ 550 fL	81	36	44	81	50	62	81	47	58

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TABLE D-20
Size Group I - Statistical Analysis

When Pairwise Comparing 8" and 12" Red-Reds	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
8" @ 620 fL & 12" @ 275 fL	22	59	33	48	2.573	0.097
8" @ 1240 fL & 12" @ 550 fL	31	50	36	45	0.047	-
In Daylight - 450 ft. Visibility Fog						
8" @ 620 fL & 12" @ 275 fL	21	60	40	41	8.519	0.004
8" @ 1240 fL & 12" @ 550 fL	42	39	50	31	1.233	-
In Darkness - Clear Weather - Rural Simulation						
8" @ 620 fL & 12" @ 275 fL	25	56	39	42	5.812	0.016
8" @ 1240 fL & 12" @ 550 fL	29	52	47	34	7.163	0.008

1 inch = 2.5 cm
1 foot = .3 meters

4) 8"[*] heads were displayed at 620fL and at 1240fL.

5) 12"[*] heads were displayed at 275fL and at 550fL.

6) Each display was presented for 3-1/2 seconds at 420 feet.[*]

7) Test subjects were asked to note the target that held their attention the longest.

5.2 Size Test Group II

Test conditions were as follows:

1) All primary targets were red-blue.

2) All targets flashed at 55/min.

3) One pair was 8"[*] heads and one pair was 12"[*] heads.

4) 8"[*] heads were displayed at 275fL and at 550fL.

5) 12"[*] heads were displayed at 275fL and at 550fL.

6) Each display was presented for 4-1/2 seconds at 420 feet.[*]

7) Test subjects were asked to note the target that held their attention the longest.

Test scores are shown in Tables D-21 and D-22.

5.3 Size/Luminance Discussion

Analyzing the daytime results of group I, it is that the dimmer 12"[*] head (275 fL) is the significant choice to overcome the decoy set competition over the brighter 8"[*] head (620fL). It is also preferable, though not significantly over the 8"[*] (1240 fL) head where the 8"[*] head luminance is 1240/275=4.52 times that of the 12"[*] head. Increasing the luminance (doubling) of the 12"[*] head does little to increase its preference. The conclusion is, at the luminance levels tested, to overcome competition in daytime, increase the size to meet that of the competition, with luminance being secondary factor. The incremental difference in 12"[*] red-red, at 275 fL and 550 fL seems to add additional credence to this conclusion, i.e., go 14"[*] or 16"[*] heads.

[*] 8 inches = 20.3 cm
12 inches = 30.5 cm
420 feet = 128.1 meters
14 inches = 35.6 cm
16 inches = 40.6 cm

TABLE D-21

Size Group II - Test Scores

Target	Daylight - Clear			Daylight - Fog			Nighttime - Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	Yes
8" Red-Blue @ 275 fL	63	32	51	63	26	41	63	35	56
8" Red-Blue @ 550 fL	63	38	60	63	37	59	63	29	46
12" Red-Blue @ 275 fL	63	42	67	63	47	75	63	37	59
12" Red-Blue @ 550 fL	63	47	75	63	58	92	63	41	65

TABLE D-22

Size Group II - Statistical Analysis

When Pairwise Comparing 8" Heads & 12" Heads	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
8" @ 275 fL & 12 " @ 550 fL	32	31	42	21	2.652	-
8" @ 550 fL & 12" @ 550 fL	38	25	47	16	2.314	-
In Daylight - 450 ft. Visibility Fog						
8" @ 275 fL & 12" @ 275 fL	26	37	47	16	13.027	< 0.001
8" @ 550 fL & 12" @ 550 fL	37	26	58	5	17.114	< 0.001
In Darkness - Clear Weather - Rural Simulation						
8" @ 275 fL & 12" @ 275 fL	35	28	37	26	0.032	-
8" @ 550 fL & 12" @ 550 fL	29	34	41	22	3.889	0.049

1 inch = 2.5 cm
1 foot = .3 meters

Daytime fog results indicates that luminance is still a secondary factor but of more importance, i.e., the 8"*(1240 fL) heads with 4.52 times the luminance of the 12"*(275 fL) heads were the subject choices. Note, also, a greater benefit in doubling the luminance of both the 8"*and 12"*heads, i.e., increased percentage of test subject choice.

Nighttime data revealed little payoff in increasing the size 8" to 12" unless the luminance (bulb wattage) is also increased. Doubling the luminance of the 8"*heads means very little. Doubling the luminance of the 12"*heads, at least as large as the competition, resulted in a considerable increase in subject selection frequency.

Test Group II confounded the Group I Test by adding another color and hence could be termed a color/size/luminance test. It was designed to build upon the results of the first test group. The appearance of a completely inconsistent anomoly in the night data, relative choice frequency of an 8"*(275 fL) red-blue pair over the brighter 8"*(550 fL) red-blue pair, indicates high probability of a miss-calibrated 8"*(275 fL) target during the nighttime tests, i.e., the target was not actually set at 275 fL, but much higher! Excluding that primary target at nighttime, the results are not inconsistent with Group I results. However, the red-blue 8"*pair fared far better with their 12"*counterparts, than they did in Group I when red-red pairs were tested.

* 8 inches = 20.3 cm
12 inches = 30.5 cm

6.0 SIZE/PLACEMENT TESTS

There were two size/placement tests. Unfortunately, on the first day of these tests, the indoor fog chamber temperature was 92°F by mid-afternoon. It was concluded that work crew nor test subjects could survive 1-1/2 hours of 100 percent humidity. The fog tests were therefore omitted.

6.1 Size/Placement Test Results - Group I

The test conditions were:

1) All primary targets were red-red or red-blue.
2) All targets flashed at 55/min.
3) All targets were displayed at 550 fL daylight and 275 fL night.
4) All targets were presented an equal number of times in the low right (9' high), high right (17' high) and high center (17' high) positions.
5) Each display was presented for 4-1/2 seconds. Test subjects were asked to note the target that held their attention longest.

6.1.1 Size/Color Results

The results of the group one test is presented in two manners. The first of these is to sum across the placements and compare the size. These results are shown in Tables D-23 and D-24.

The results shown in Table D-23 indicate complete consistency with prior results, except (once again) for the 8" red-blue flashing pair which, based upon;

1) Its choice in daytime over the 8" red-red (not consistent with prior results),

and

2) Its choice at night, over both the 12" red-red and 12" red-blue (not consistent with prior results),

collectively indicate a considerably "hot"* miscalibrated 8" red-blue target.

92° F = 33.3° C
9 feet = 2.7 meters
17 feet = 5.2 meters
8 inches = 20.3 cm
12 inches = 30.5 cm

*Very Bright

TABLE D-23

Size/Placement Group I - Test Scores

Target	Daylight-Clear			Night-Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
8" Red-Red	96	25	26	48	15	31
8" Red-Blue	96	36	38	48	30	63
12" Red-Red	96	49	51	48	24	50
12" Red-Blue	96	48	50	48	26	54

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TABLE D-24

Size Group I - Test Scores

When Pairwise Comparing 8" Heads & 12" Heads	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
8" Red-Red & 12" Red-Red	25	71	49	47	11.632	< 0.001
8" Red-Blue & 12" Red-Blue	36	60	48	48	2.561	--
In Darkness - Clear Weather - Rural Simulation						
8" Red-Red & 12" Red-Red	15	33	24	24	2.764	-
8" Red-Blue & 12" Red-Blue	30	18	26	22	0.385	-

1 inch = 2.5 cm

If the 8"* red-blue target results are discarded, comparison of the remaining three primary targets, one 8"* red-red and two 12"* red-red and 12"* red-blue targets indicate results consistent with prior testing.

6.1.2 Placement Results (Group I)

Summing across the 8"* red-red, 8"* red-blue, 12"* red-red and 12"* red-blue to deduce some preferable position placement seems unreasonable in lieu of prior discussion. However, presentation of this summartion will not reflect upon the general placement conclusions. This summation of results is presented in Table D-25. Analysis with the "hot 8"* red-blue target" included, is shown in Table D-26.

6.1.3 Size Results (Group I)

To sum across red-red and red-blue and compare 8"* and 12"* heads makes little sense, since results would be contaminated by the "hot" 8"* red-blue pair of lights.

6.2 Size/Placement Test (Group II)

Two groups of test subjects compared conspicuity of three different placements of targets. Test conditions were;

1) High center (17 ft* high) placement
2) High right (17 ft* high) placement
3) Low right (9 ft* high) placement
4) Primary targets were 8"* and 12"* red-red and red-blue
5) All targets were displayed at 550 fL in daylight and 275 fL at night.

Each display was presented for 4-1/2 seconds, at 420 feet*. Test subjects were asked to choose the target that held their attention longest.

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* 8 inches = 20.3 cm
12 inches = 30.5 cm
17 feet = 5.2 meters
9 feet = 2.7 meters
420 feet = 128.1 meters

TABLE D-25

Placement Group I - Test Scores

Target	Daylight-Clear			Nighttime-Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
Top Center	128	62	48	64	45	70
Top Right	128	39	30	64	25	39
Lower Right	128	61	48	64	24	38

TABLE D-26

Placement Group I - Statistical Analysis

Comparing flashing light at different placements	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ difference is significant at level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
Top Center and Lower Right	62	66	61	67	0.000	-----
Top Center and Top Right	62	66	39	89	7.915	0.005
Lower Right and Top Right	61	67	39	89	7.237	
In Darkness - Clear Weather - Rural Simulation						
Top Center and Top Right	45	19	25	39	11.381	<0.001
Top Center and Lower Right	45	19	24	40	12.577	<0.001
Top Right and Lower Right	24	40	25	39	0.000	-----

6.2.1 Size/Color Results (Group II)

The size/color balance of test group II was not maintained and hence presentation of these comparisons would be biased.

6.2.2 Placement Results (Group II)

Summing over size and colors the three placement positions were subject scored as shown in Table D-27. Analysis of these scores are shown in Table D-28.

6.2.3 Size Results (Group II)

Summing over placements (three) and colors (two) subject test scores and analysis of 8"* versus 12"* heads are shown in Tables D-29 and D-30.

6.3 Discussion

The two primarily placement tests were confounded by both 8"* and 12"* heads with both red-red and red-blue flashing light pairs. A "hot" 8"* red-blue pair contaiminated the first group tests.

The second group test in terms of comparison of 8"* and 12"* at the same luminance does conform with results in previous sections. Daylight and nighttime results indicate some highly competitive decoy targets, while daylight fog conditions reveal the red-red and red-blue pairs attracting more subject attention. Choice of the larger 12"* heads over the smaller 8"* heads in the daytime fog condition is shown in Table D-24.

The top center (cantalevered) placement is consistently preferred at night. Daytime (clear) conditions have differing results regarding the choice of high center versus low right placements. The one daylight fog test revealed a subject preference for lower right placement. The foregoing is not inconsistent with the real world

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* 8 inches = 20.3 cm
12 inches = 30.5 cm

i. e., there is generally less light competition over the roadway at night while much nighttime light competition is not even lit during the daytime. Daytime fog, reduced visibility conditions, may well indicate the importance the driver attaches to the right side of the roadway--at a "standard height."

TABLE D-27

Placement Group II - Test Scores

8" Device	Daylight - Clear			Daylight - Fog			Nighttime-Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
Top Center	56	11	20	144	39	27	128	29	23
Top Right	56	9	16	144	33	23	128	18	14
Lower Right	56	19	34	144	51	35	128	7	13

TABLE D-28

Placement Test Group II - Statistical Analysis

Comparing flashing lights at different placements	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ difference is significant at level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
Lower Right and Top Center	19	37	11	45	2.231	-----
Lower Right and Top Right	19	37	9	47	3.857	0.050
Top Center and Lower Right	11	45	9	47	0.061	-----
In Daylight - 450 ft Visibility Fog						
Lower Right and Top Center	51	93	39	105	1.956	-----
Lower Right and Top Right	51	93	33	111	4.857	0.028
Top Center and Top Right	39	105	33	111	0.463	-----
In Darkness - Clear Weather - Rural Simulation						
Top Center and Top Right	29	99	18	110	2.606	-----
Top Center and Lower Right	29	99	19	109	2.077	-----
Top Right and Lower Right	18	110	19	109	0.000	-----

1 inch = 2.5 cm
1 foot = .3 meters

TABLE D-29

Size Group II - Test Scores

Target	Daylight - Clear			Daylight - Fog			Nighttime - Clear		
	Sample Size	Yes	% Yes	Sample Size	Yes	Yes	Sample Size	Yes	% Yes
8" Heads	84	15	18	192	43	22	96	29	30
12" Heads	84	24	29	192	80	42	96	35	36

TABLE D-30

Size Group II - Statistical Analysis

When Pairwise Comparing 8" Heads & 12" Heads	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
12" Heads & 8" Heads	24	60	15	69	2.137	-
In Daylight - 450 ft. Visibility Fog						
12" Heads & 8" Heads	80	112	43	149	15.502	≤ 0.001
In Darkness - Clear Weather - Rural Simulation						
12" Heads & 8" Heads	35	61	29	67	0.586	-

1 inch = 2.5 cm
1 foot = .3 meters

7.0 COLORED STROBES

Two test groups were used to compare conspicuity of colored, alternately flashing xenon flash lamps. Red-red and red-blue pairs were chosen for testing.

The xenon strobes were fixed at the optimum focal point of the mirror reflector of a standard traffic signal head. Peak voltage across the flashtubes was about 340 volts. Red lenses with minimum acceptable hue* and medium blue lens* were chosen for the laboratory testing. The low voltage flash and light hue lens combination was selected to provide the greatest penetration of light through the red lens.

With each test group, four strobe light flashrate-intensity combinations plus one pair of standard railroad incandescent flashers made up the five primary targets for comparison.

7.1 Colored Strobe Test Group I

Test conditions were:

1) All four xenon strobe combinations were red-red.
2) All lens were 8-inch** diameter.
3) The incandescent railroad pair used high efficiency reflectorized blubs as shown on Figure D-1 and presented high luminance reading (32,000 fL) at beam center.

All targets were presented for 4-1/2 seconds. Test subjects noted that the target that held their attention longest.

The test group scores and their statistical comparison are shown in Tables D-31 and D-32. Only the red-red strobe at 17 Joules and flashrate of 110/minute could approach the test subject selection frequency of the 8-inch** flashing incandescent pair of railroad heads (daytime and nighttime).

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*See Glossary

** 8 inches = 20.3 cm

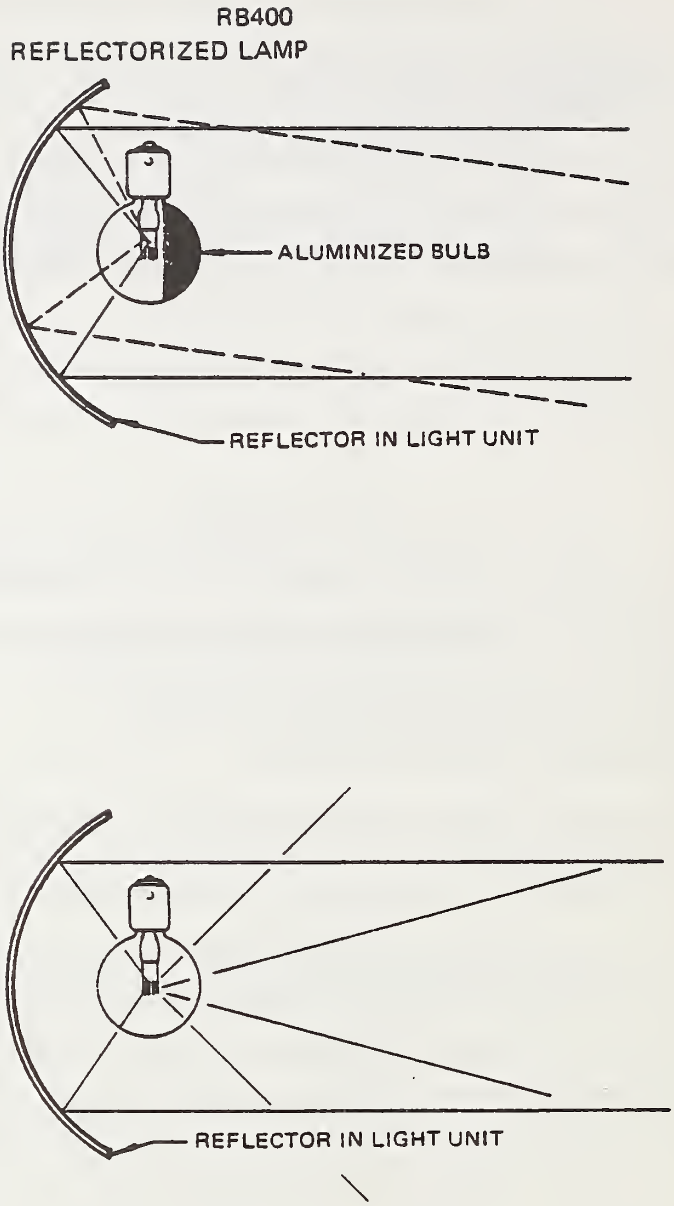

FIGURE D-1
18 WATT 10 VDC TUNGSTEN
FILAMENT SIGNAL BULBS

TABLE D-31

Strobes Group I - Test Scores

#	Targets	Daylight-Clear			Daylight-Fog			Night-Clear		
		Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
1	8" Railroad Pair @ 55/min & 32K fL	81	15	19	81	42	52	81	17	21
2	Red-red strobe @ 110/min & 17J	81	14	17	81	35	43	81	17	21
3	Red-red strobe @ 55/min & 17J	81	14	17	81	19	23	81	1	1
4	Red-red strobe @ 110/min & 9J	81	4	5	81	18	22	81	9	11
5	Red-red strobe @ 55/min & 9J	81	1	1	81	7	9	81	4	5

1 inch = 2.5 cm

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TABLE D-32
Strobes - Group I - Statistical Analysis

Comparing red-red strobe lights	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ difference is significant at level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
1 & 2	15	66	14	67	0.000	-----
1 & 3	15	66	14	67	0.000	-----
1 & 4	15	66	4	77	5.962	0.015
1 & 5	15	66	1	80	11.720	<0.001
2 & 3	14	67	14	67	0.043	-----
2 & 4	14	67	4	77	5.063	0.024
2 & 5	14	67	1	80	10.580	0.001
3 & 4	14	67	4	77	5.063	0.024
3 & 5	14	67	1	80	10.580	0.001
4 & 5	4	77	1	80	0.825	-----
In Daylight - 450 ft Visibility Fog						
1 & 2	42	39	35	46	0.891	-----
1 & 3	42	39	19	62	12.727	<0.001
1 & 4	42	39	18	63	14.003	<0.001
1 & 5	42	39	7	74	33.822	<0.001
2 & 3	35	46	19	62	6.250	0.012
2 & 4	35	46	18	63	7.179	0.007
2 & 5	35	46	7	74	23.432	<0.001
3 & 4	19	62	18	63	0.000	-----
3 & 5	19	62	7	74	5.544	0.019
4 & 5	18	63	7	74	4.730	0.030
In Darkness - Clear Weather - Rural Simulation						
1 & 2	17	64	17	64	0.037	-----
1 & 3	17	64	1	80	14.063	<0.001
1 & 4	17	64	9	72	2.245	-----
1 & 5	17	64	4	77	7.878	0.005
2 & 3	17	64	1	80	14.063	<0.001
2 & 4	17	64	9	72	2.245	-----
2 & 5	17	64	4	77	7.878	0.005
3 & 4	1	80	9	72	5.222	0.022
3 & 5	1	80	4	77	0.825	-----
4 & 5	9	72	4	77	1.338	-----

Target No. 1: 8" Railroad Pair at 55/min. & 32K fL; Target No. 2: Red-Red Strobe at 110/min. & 17J; Target No. 3: Red-Red Strobe at 110/min & 17J; Target No. 4: Red-Red Strobe at 110/min. & 9J; Target No. 5: Red-Red Strobe at 55/min. & 9J.

1 foot = .3 meters
1 inch = 2.5 cm

The red strobes did not score nearly as well as had been expected.

The brightest red strobes used 62 watts of energy at the light source (17 Watt-Seconds x 1.83 flashes/second x 2 lights).

The standard railroad pairs used 18 watts of energy.

7.2 Color Strobe Test Group II

A second test group went through the same test design excepting that one of the two red strobe filters was replaced by a medium blue filter.

Results are shown in Tables D-33 and D-34.

When replacing one red lens with a blue lens, the quantity of light transmitted through the blue lens was about three times that of the red lens. As shown in Figure B-5, Appendix B, a xenon tube produces more than three times as much light in the blue-violet regions than it does in the red regions. With red-blue lenses the strobes become very competitive with the railroad incandescent flashing pair of lights.

TABLE D-33

Strobes Group II - Test Scores

#	Target	Daylight - Clear			Daylight-Fog			Night-Clear		
		Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
1	Red-Blue Strobe @ 110/min. & 17J	81	33	41	81	44	54	81	38	47
2	8" Railroad Pair @ 55/min. & 32K fL	81	29	36	81	44	30	81	17	21
3	Red-Blue Strobe @ 55/min. & 17J	81	18	22	81	35	43	81	27	33
4	Red-Blue Strobe @ 110/min. & 9J	81	20	25	81	10	12	81	22	27
5	Red-Blue Strobe @ 55/min. & 9J	81	10	12	81	7	9	81	10	12

1 inch = 2.5 cm

TABLE D-34

Strobe Group II - Statistical Analysis

Comparing Red-Blue Strobe Lights	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Rural Simulation						
1 & 2	33	48	29	52	0.235	-
1 & 3	33	48	18	63	5.609	0.018
1 & 4	33	48	20	61	4.038	0.044
1 & 5	33	48	10	71	15.323	< 0.001
2 & 3	29	52	18	63	2.997	0.083
2 & 4	29	52	20	61	1.872	-
2 & 5	29	52	10	71	10.942	0.001
3 & 4	18	63	20	61	0.034	-
3 & 5	18	63	10	71	2.116	-
3 & 5	20	61	10	71	3.314	0.069
In Daylight - 450 ft. Visibility Fog						
1 & 2	44	37	24	57	9.149	0.003
1 & 3	44	37	35	46	1.581	-
1 & 4	44	37	10	71	30.251	< 0.001
1 & 5	44	37	7	74	37.057	< 0.001
2 & 3	24	57	35	46	2.666	-
2 & 4	24	57	10	71	6.291	0.012
2 & 5	24	57	7	74	10.212	< 0.001
3 & 4	35	46	10	71	17.723	< 0.001
3 & 5	35	46	7	74	23.432	< 0.001
4 & 5	10	71	7	74	0.263	-

Target No. 1:	Red-Blue Strobe at 110/min. & 17J.
Target No. 2:	8" Railroad Pair at 55/min. & 32 K fL.
Target No. 3:	Red-Blue Strobe at 55/min. & 17J.
Target No. 4:	Red-Blue Strobe at 110/min. & 9J.
Target No. 5:	Red-Blue Strobe at 55/min. & 9J.

1 foot = .3 meters
1 inch = 2.5 cm

TABLE D-34 (Continued)

Comparing Red-Blue Strobes	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Darkness - Clear Weather - Rural Simulation						
1 & 2	38	43	17	64	11.001	< 0.001
1 & 3	38	43	27	54	2.569	-
1 & 4	38	43	22	59	3.598	0.058
1 & 5	38	43	10	71	21.582	< 0.001
2 & 3	17	64	27	54	2.527	-
2 & 4	17	64	22	59	0.540	-
2 & 5	17	64	10	71	1.600	-
3 & 4	27	54	22	59	0.468	-
3 & 5	27	54	10	71	8.967	0.003
4 & 5	22	59	10	71	4.712	0.030

Target No. 1:	Red-Blue Strobe at 110/min. & 17J.
Target No. 2:	8" Railroad Pair at 55/min. & 32 K fL.
Target No. 3:	Red-Blue Strobe at 55/min. & 17J.
Target No. 4:	Red-Blue Strobe at 110.min. & 9J.
Target No. 5:	Red-Blue Strobe at 55/min. & 9J.

1 inch = 2.5 cm

8.0 NOVEL FLASHING LIGHTS

Development and selection of novel flashing displays began with the assumption that they would likely supplement the traditional railroad signal pairs rather than replace them. Therefore, all novel devices tested were installed on a "standard"* and tested in combination with conventional railroad incandescent flashing lights.

Many novel ideas for improved grade crossing signals had been developed, and it was decided to select the few most promising for evaluation in this series of tests. To make these selections, pilot tests were performed using displays of some 25 variations of strobes and incandescent lights. University of California personnel, working in nearby buildings, graciously volunteered their time and judgements for these pilot tests. California Public Utilities and FHWA personnel visiting the test site also participated in the final stages of this selection process.

These pilot tests led to the following judgements relevant to signal selections for subsequent testing:

1) White strobes appeared more powerful than any of the other colors.

2) Flashrates (strobes) exceeding 110/min. appeared reasonable and more conspicuous than slower rates.

3) Irregular time intervals between flashes of the faster flashrates appeared less annoying and just as conspicuous as regular intervals.

4) Apparent motion of the strobe flashes seemed to improve conspicuity. That apparent motion was achieved by flashing two side by side strobe lights at short time intervals. When the strobes were 12"** to 18"** apart, motion was much more apparent than when the strobes were 24"** to 30"** apart.

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*See Glossary

** 12 inches = 30.5 cm
18 inches = 45.7 cm
24 inches = 61 cm
30 inches = 76.2 cm

8.1 Novel Flashing Light - Test Group I

The first test group to compare Novel Flashing Lights compared five primary displays, one of which was a standard railroad alternating signal pair flashing at 55/min. and luminance of 32 K fL. The other four displays all added flashing strobe lights to that railroad signal pair. One strobe was a Rae Strobe Company's Halo (strobe) light shown in Figure D-2 as well as 8"* white and 8"* red strobe lights in various configurations. The four strobe configurations, each with an 8" railroad pair, are shown in Figures D-3 through D-6.

All displays were presented for 4-1/2 seconds at 420 feet.* Test subjects were asked to note the target that held their attention longest. Test scores for the Group I test are shown in Tables D-35 and D-36.

Conclusions of test group were:

1) All combinations of white and halo strobes supplementing railroad pairs added significantly to the conspicuity of the railroad pairs.
2) The single red strobe at 55/min. added no appreciable conspicuity to the railroad pairs.
3) As shown on Tables D-35 and D-36, the triple white strobe was the most effective add-on device to the railroad lights.

The design of the triple strobe supplementing the railroad pair (see Figure D-3), considered all of the findings from the pilot tests. Spacing, color, flashrate, redundancy, and timing of the strobes were all considered important to increased conspicuity.

When comparing the triple and single strobe targets, the redundancy and apparent movement of the triple strobe appeared to be very important in daylight, of lesser value in the fog and of questionable value at night (white strobe power was likely far beyond what is needed at night). This suggests that trial installations of strobe lights at rural railroad crossings would certainly incorporate <u>nighttime reduction of energy</u> per discharge flash.

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* 8 inches = 20.3 cm
420 feet = 128.1 meters

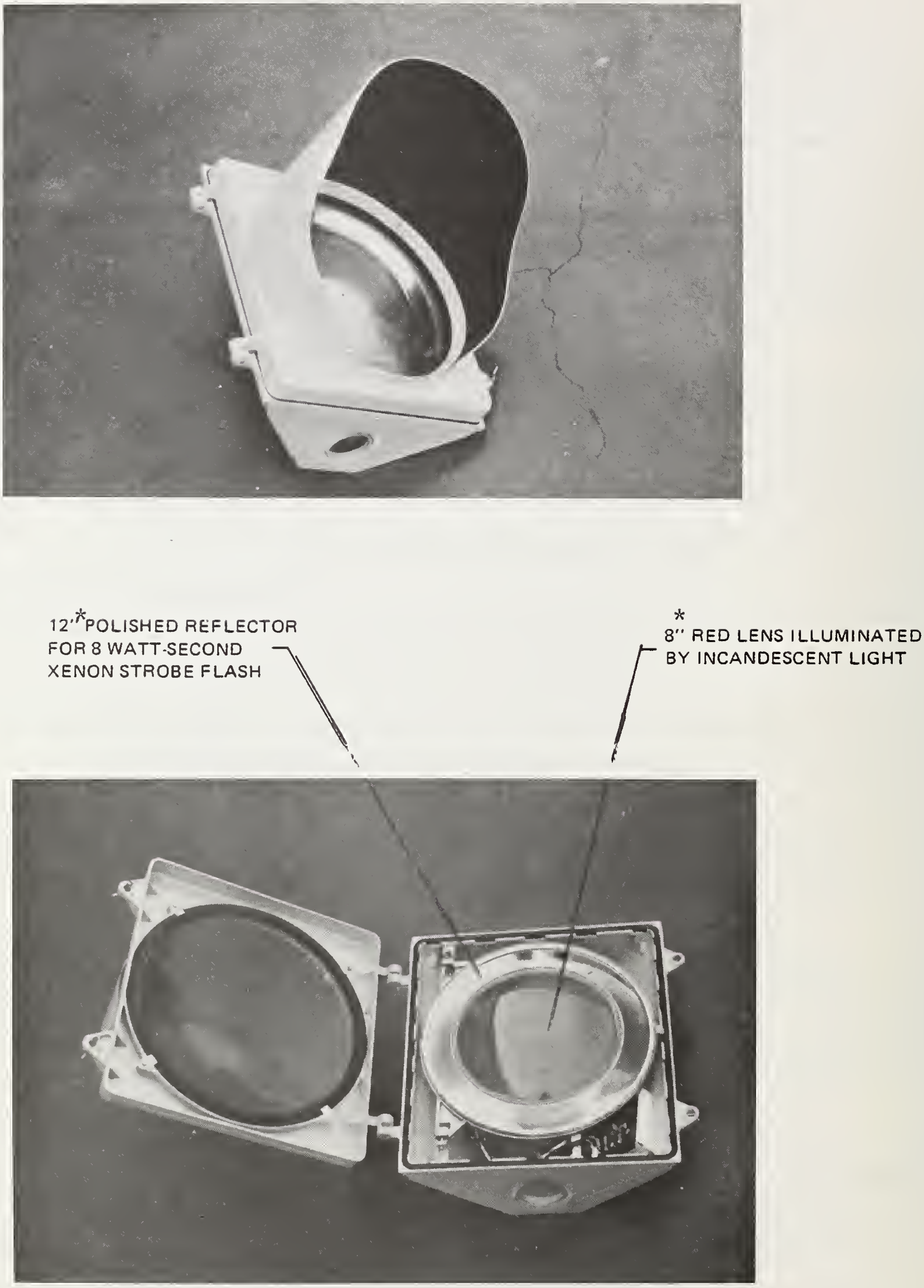

FIGURE D-2
HALO STROBE

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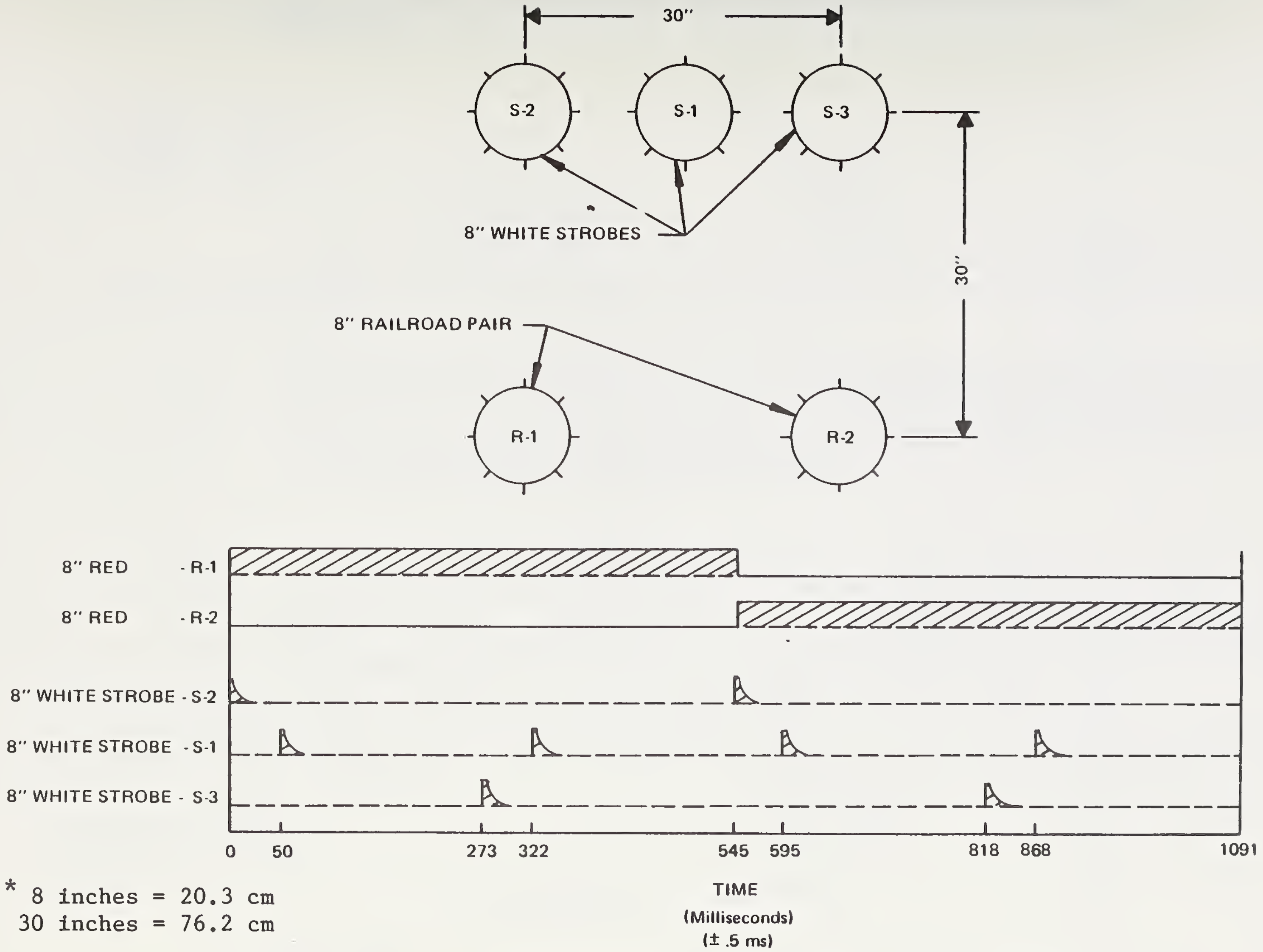
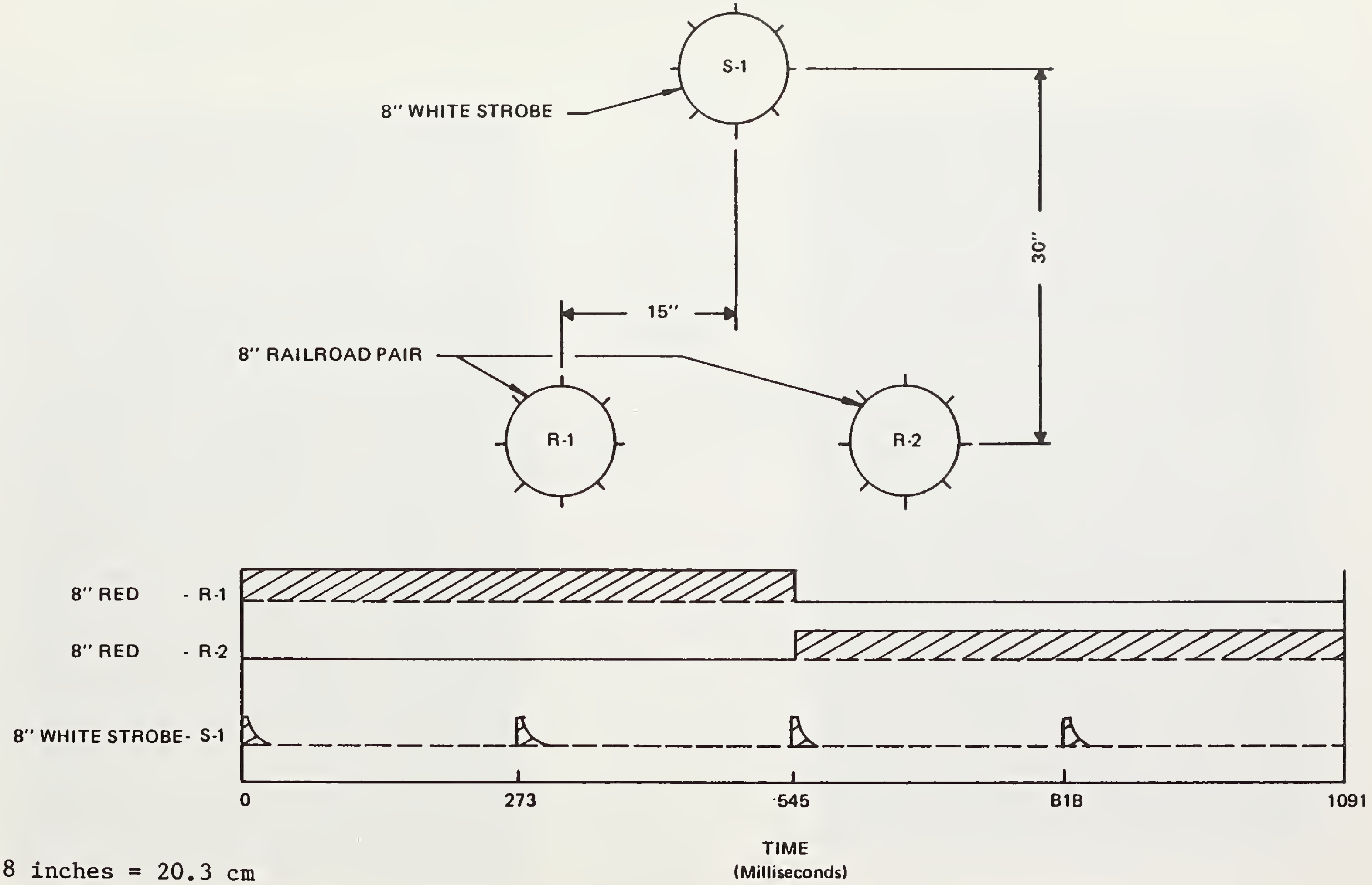
* 12 inches = 30.5 cm
8 inches = 20.3 cm



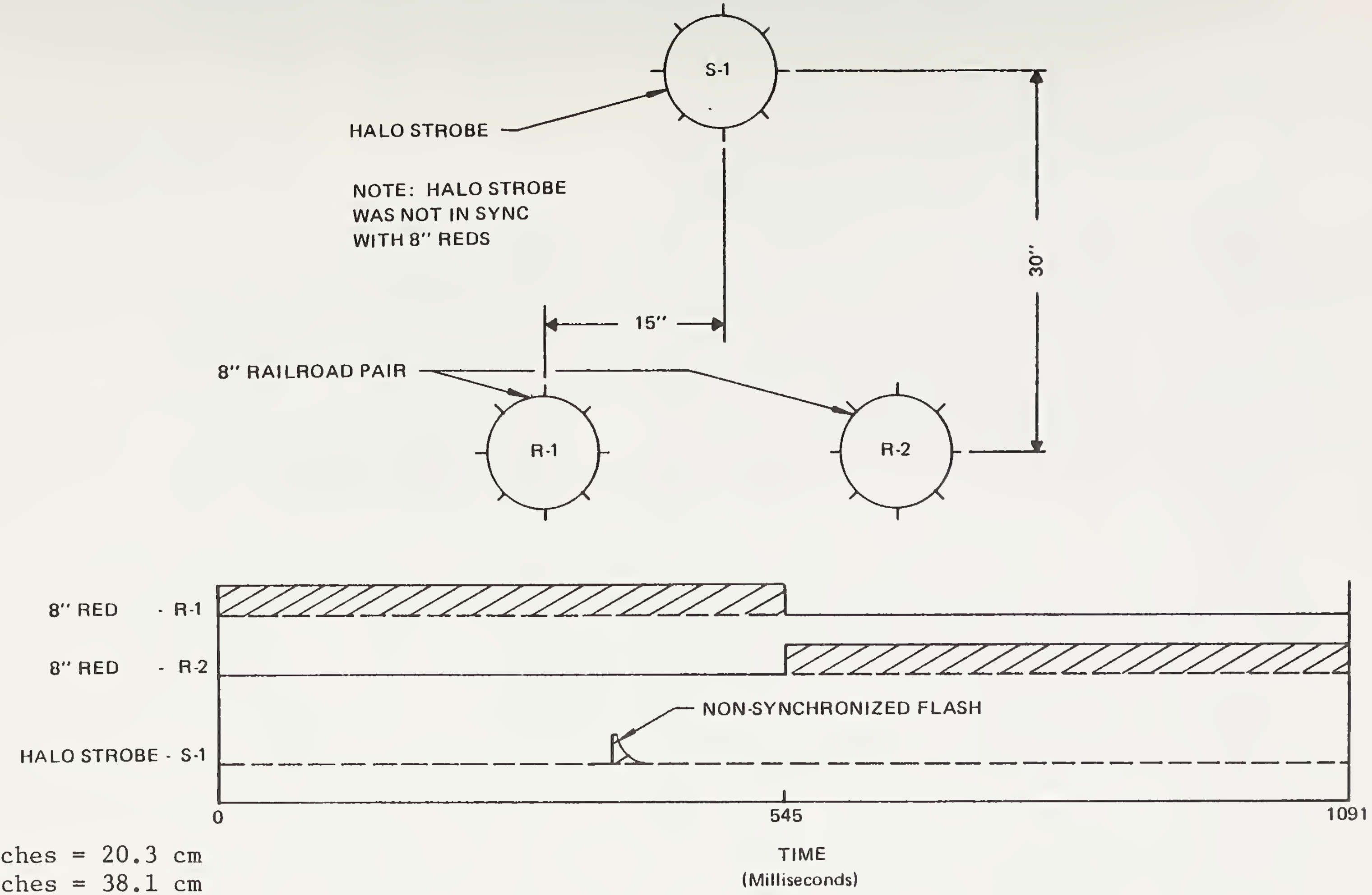
* 8 inches = 20.3 cm
30 inches = 76.2 cm

FIGURE D-3
TRIPLE STROBE AND RAILROAD LIGHT CONFIGURATION & FLASHING CYCLE



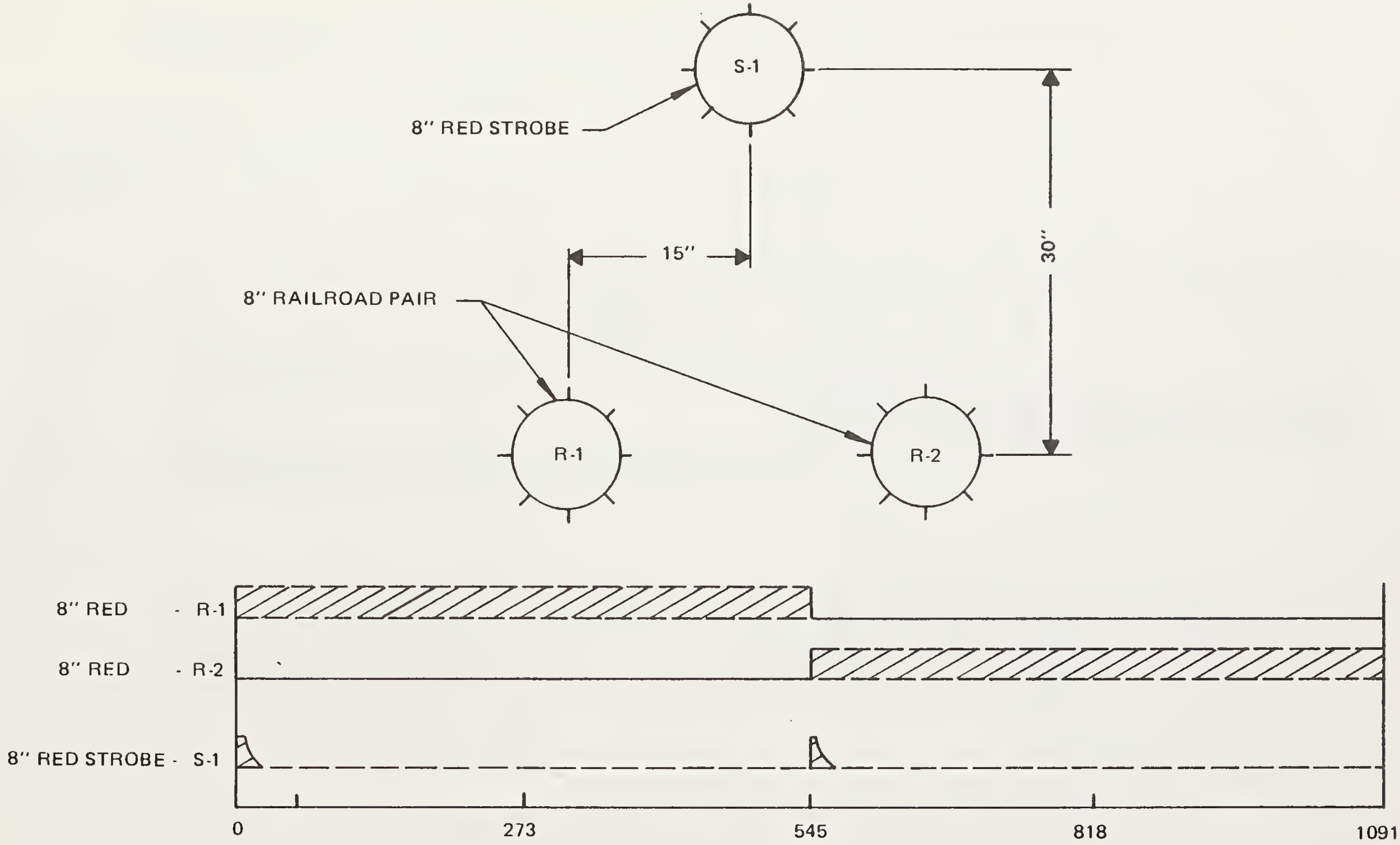
* 8 inches = 20.3 cm
30 inches = 76.2 cm
15 inches = 38.1 cm

FIGURE D-4
SINGLE STROBE AND RAILROAD LIGHT CONFIGURATION & FLASHING CYCLE



*
8 inches = 20.3 cm
15 inches = 38.1 cm
30 inches = 76.2 cm

FIGURE D-5
HALO STROBE AND RAILROAD LIGHT CONFIGURATION & FLASHING CYCLE



*
8 inches = 20.3 cm
15 inches = 38.1 cm
30 inches = 76.2 cm

FIGURE D-6
SINGLE RED STROBE AND RAILROAD LIGHT CONFIGURATION & FLASHING CYCLE

TABLE D-35

Novel Flashing Light Group I - Test Scores

#	Target	Daylight - Clear			Daylight - Fog			Nighttime - Clear		
		Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	Yes
1	3 Strobes & 2 R R Reds (Fig. D-3)	81	55	68	81	71	88	81	59	73
2	1 Strobe & 2 R R Reds (Fig. D-4)	81	35	43	81	68	84	81	64	79
3	1 Halo Strobe & 2 R R Reds (Fig. D-5)	81	38	47	81	47	58	81	34	42
4	8" Railroad Pair (See Below)	81	15	19	81	25	31	81	12	15
5	1 Red Strobe & 2 R R Reds (Fig. D-6)	81	10	12	81	31	38	81	18	22

Target No. 1: Standard RR pair with 3 white strobes as per Figure D-3. Center strobe at 9 Joules. Outside strobes at 17J.

Target No. 2: Standard RR pair with 1 white strobe as per Figure D-4. Strobes at 9 Joules.

Target No. 3: Standard RR pair with single Halo strobe at 55/min. and at 8J, as per Figure D-5.

Target No. 4: Standard RR pair at 55/min. and at 32 K fL.

Target No. 5: Standard RR pair with single red strobe at 110/min. and at 17J, as per Figure D-6.

1 inch = 2.5 cm

TABLE D-36

Novel Flashing Light Group I - Statistical Analysis

Comparing Pairs of Novel Flashing Lights	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		

In Daylight - Clear Weather - Rural Simulation

1 & 2	55	26	35	46	9.025	0.003
1 & 3	55	26	38	43	6.463	0.011
1 & 4	55	26	15	66	38.261	<0.001
1 & 5	55	26	10	71	49.743	<0.001
2 & 3	35	46	38	43	0.100	-
2 & 4	35	46	15	66	10.443	0.001
2 & 5	35	46	10	71	17.723	<0.001
3 & 4	38	43	15	66	13.572	<0.001
3 & 5	38	43	10	71	21.582	<0.001
4 & 5	15	66	10	71	0.757	-

In Daylight - 450 ft. Visibility Fog

1 & 2	71	10	68	13	0.203	-
1 & 3	71	10	47	34	16.506	<0.001
1 & 4	71	10	25	56	51.776	<0.001
1 & 5	71	10	31	50	40.262	<0.001
2 & 3	68	13	47	34	11.989	<0.001
2 & 4	68	13	25	56	44.533	<0.001
2 & 5	68	13	31	50	33.662	<0.001
3 & 4	47	34	25	56	11.025	<0.001
3 & 5	47	34	31	50	5.563	0.018
4 & 5	25	56	31	50	0.682	-

Target No. 1:	Standard RR pair with 3 white strobes as per Figure D-3. Center strobe at 9 Joules. Outside strobes at 17J.
Target No. 2:	Standard RR pair with 1 white strobe as per Figure D-4. Strobes at 9 Joules.
Target No. 3:	Standard RR pair with single Halo strobe at 55/min. and at 8J, as per Figure D-5.
Target No. 4:	Standard RR pair at 55/min. and at 32 K fL.
Target No. 5:	Standard RR pair with single red strobe at 110/min. and at 17J, as per Figure D-6.

TABLE D-36 Continued

Comparing Pairs of Novel Flashing Lights	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Darkness - Clear Weather - Rural Simulation						
1 & 2	59	22	64	17	0.540	-
1 & 3	59	22	34	47	14.541	<0.001
1 & 4	59	22	12	69	53.055	<0.001
1 & 5	59	22	18	63	39.603	<0.001
2 & 3	64	17	34	47	21.722	<0.001
2 & 4	64	17	12	69	14.468	<0.001
2 & 5	64	17	18	63	50.008	<0 001
3 & 4	34	47	12	69	13.389	<0.001
3 & 5	34	47	18	63	6.372	0.012
4 & 5	12	69	18	63	1.023	-

Target No. 1:	Standard RR pair with 3 white strobes as per Figure D-3. Center strobe at 9 Joules. Outside strobes at 17J.
Target No. 2:	Standard RR pair with 1 white strobe as per Figure D-4. Strobes at 9 Joules.
Target No. 3:	Standard RR pair with single Halo strobe at 55/min. and at 8J, as per Figure D-5.
Target No. 4:	Standard RR pair at 55/min. and at 32 K fL.
Target No. 5:	Standard RR pair with single red strobe at 110/min. and at 17J, as per Figure D-6.

1 foot = .3 meters

8.2 Novel Flashing Light - Test Group II

A second test group was used to compare the three white strobe array with different flash discharge power against both 8 inch*and 12 inch* diameter incandescent railroad flashing pairs. The tests for this group were conducted with a simulated urban background. Background clutter included roadside signs, street lighting, lighted signs, pedestrians, opposing traffic, oposing headlights, buildings, etc. -- the background clutter appeared effective. Subsequent tests indicated that it was a reasonable simulation based on the frequency with which test subjects chose background objects rather than test targets.

Fog tests were again deleted for this test group because the temperature was 95°*and 1-1/2 hours of tests at 100 percent humidity would have subjected test personnel to an unreasonable amount of discomfort.

All displays were presented for 4-1/2 seconds at 420 feet.* Test subjects chose the target or object that held their attention the longest.

Test scores for this group are shown in Tables D-37 and D-38. The analysis of scores of these tests, made in a simulated urban environment, indicate:

1) The 12 inch*diameter railroad pairs were significantly more conspicuous than the 8 inch*heads for this test group.

2) The addition of the triple strobes at both intensities added significantly to the conspicuity of the 8 inch* railroad pairs.

3) Doubling the discharged energy per strobe flash appears to have a significant effect in darkness with strong background competition, i.e., 3 Joules to 5.5 Joules.

---

* 8 inches = 20.3 cm
12 inches = 30.5 cm
95° F = 35° C
420 feet = 128.1 meters

TABLE D-37

Novel Flashing Light Group II - Test Scores

#	Target	Daylight - Clear			Nighttime - Clear		
		Sample Size	Yes	% Yes	Sample Size	Yes	& Yes
1	3 White Strobe & RR Pair (See Note)	135	86	64	135	56	41
2	3 White Strobe & RR Pair (See Note)	135	74	55	135	36	27
3	12" Railroad Pair @ 55/min.	135	45	33	135	43	32
4	8" Railroad Pair @ 55/min.	135	24	18	135	24	18

Target No. 1:	Standard 8" RR pair with 3 White Strobes as per Figure D-3 . Strobes at 11 Joules in daylight and at 5.5 Joules at night.
Target No. 2:	Standard 8" RR pair with 3 White Strobes as per Figure D-3 . Strobes at 5.5 Joules in daylight and at 3 Joules at night.
Target No. 3:	Standard 12" Railroad pair @ 55/min. & 16 K fL.
Target No. 4:	Standard 8" Railroad pair @ 55/min. & 32 K fL.

1 inch = 2.5 cm
1 foot = .3 meters

TABLE D-38

Novel Flashing Light Group II - Statistical Analysis

Comparing Pairs of Novel Flashing Lights	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Urban Simulation						
1 & 2	86	49	74	61	1.856	-
1 & 3	86	49	45	90	23.725	< 0.001
1 & 4	86	49	24	111	57.084	< 0.001
2 & 3	74	61	45	90	11.780	< 0.001
2 & 4	74	61	24	111	38.459	< 0.001
3 & 4	45	90	24	111	7.787	0.005
In Darkness - Clear Weather - Urban Simulation						
1 & 2	56	79	36	99	5.952	0.015
1 & 3	56	79	43	92	2.297	-
1 & 4	56	79	24	111	17.070	< 0.001
2 & 3	36	99	43	92	0.644	-
2 & 4	36	99	24	111	2.593	-
3 & 4	43	92	24	111	6.432	0.011

Target No. 1:	Standard 8" RR pair with 3 White Strobes as per Figure D-3 . Strobes at 11 Joules in daylight and at 5.5 Joules at night.
Target No. 2:	Standard 8" RR pair with 3 White Strobes as per Figure D-3 . Strobes at 5.5 Joules in daylight and at 3 Joules at night.
Target No. 3:	Standard 12" Railroad pair @ 55/min. & 16 K fL.
Target No. 4:	Standard 8" Railroad pair @ 55/min. & 32 K fL.

1 inch = 2.5 cm

4) The nighttime scores of this test group were much lower than their daytime scores for strobe and railroad pair combinations, i.e., the group selected background clutter more frequently at night. The most effective background competition was opposing vehicle headlights.

8.3 Novel Flashing Light - Test Group III

Tests were designed for a third test group to explore the effects of redundant strobe lights with the highly competitive background clutter. This test included an 8-inch* white strobe pair along with a railroad pair as shown in Figure D-7.

Test Group III compared single, double, and triple white strobes. The single and triple strobes were identical to those targets shown in Group I with a non-competitive background.

All displays were presented for 4-1/2 seconds at 420 feet.* Test subjects noted which target held their attention longest. Test subject scores are shown in Tables D-39 and D-40.

The analysis of Group III scores indicates:

1) In all three environments, a clear rank order was established, indicating that the redundancy of the strobes was important.

2) Redundancy appeared more important in daylight than in darkness.

3) The difference between three strobes and one strobe was clearly significant at night with the highly competitive background where the same comparisons showed no change in conspicuity with Group I (Tables D-35 and D-36) in a non-competitive background at night.

4) These results suggest that the third (center) strobe adds little to conspicuity in an urban background simulation.

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* 8 inches = 20.3 cm
420 feet = 128.1 meters

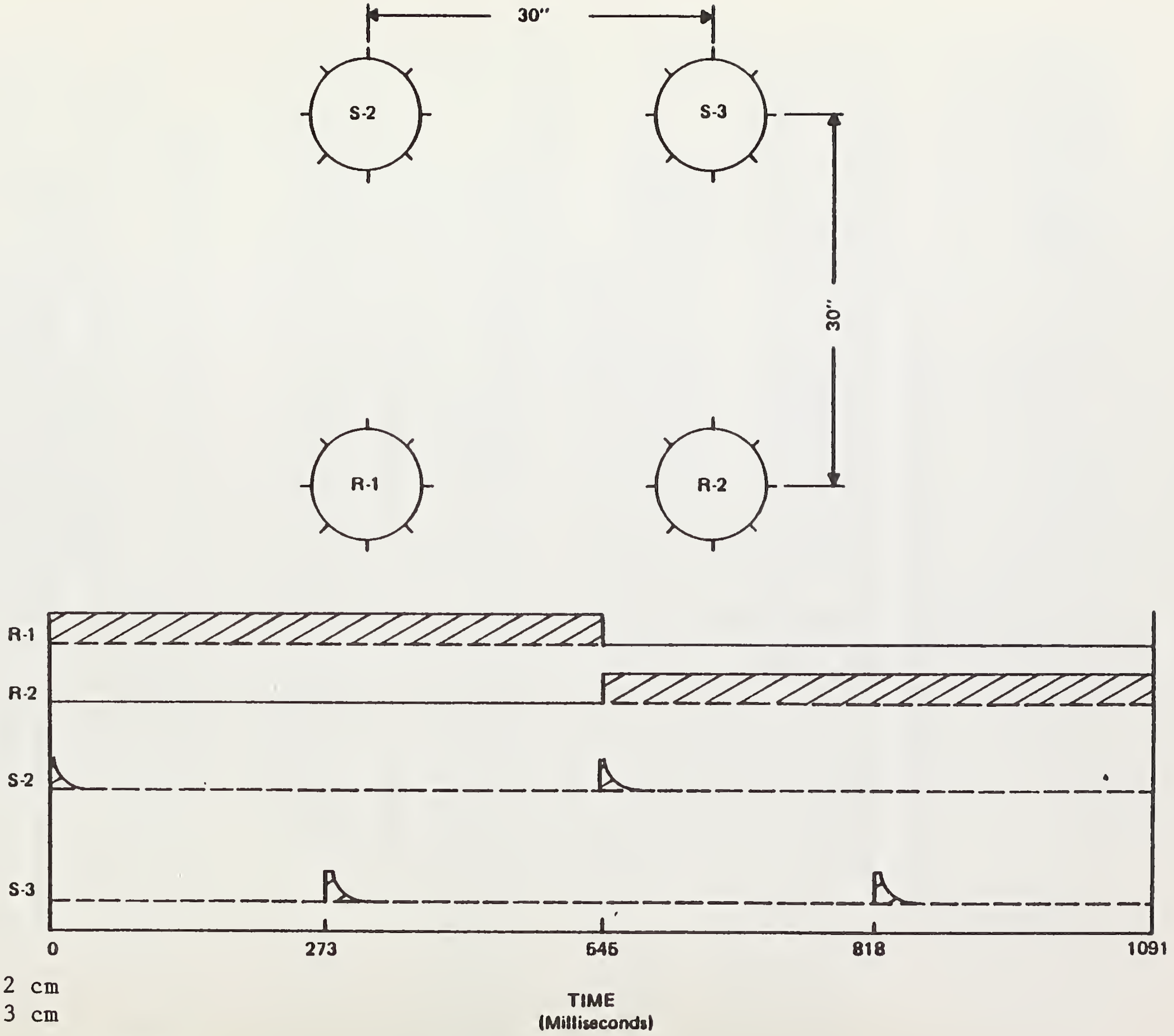


FIGURE D-7
TWO 8" WHITE STROBES AND RAILROAD LIGHT CONFIGURATION & FLASHING CYCLE

* 30 inches = 76.2 cm
8 inches = 20.3 cm

TABLE D-39

Novel Flashing Light Group III - Test Scores

#	Target	Daylight - Clear			Daylight - Fog			Nighttime - Clear		
		Sample Size	Yes	% Yes	Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
1	3 White Strobes & RR Pair	135	106	79	54	49	91	135	70	52
2	2 White Strobes & RR Pair	135	85	63	54	38	70	135	58	43
3	1 White Strobe & RR Pair	135	67	50	54	33	61	135	48	36
4	8" RR Pair @ 55/min.	135	32	24	54	11	20	135	27	20

Target No. 1: Standard 8" RR pair with 3 White strobes as per Figure D-3. Center strobe at 9 Joules. Outside strobes at 17 Joules.

Target No. 2: Standard 8" RR pair with 2 White strobes as per Figure D-7. Strobes at 110/min. and at 17 Joules.

Target No. 3: Standard 8" RR pair with single White strobe as per Figure D-4. Strobe at 220/min. and at 9 Joules.

Target No. 4: Standard 8" RR pair @ 55/min. and at 32 K fL.

1 inch = 2.5 cm

TABLE 40

Novel Flashing Light Group III - Statistical Analysis

When Comparing Devices	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Urban Simulation						
1 & 2	106	29	85	50	7.158	0.007
1 & 3	106	29	67	68	23.233	<0.001
1 & 4	106	29	32	103	78.987	<0.001
2 & 3	85	50	67	68	4.350	0.037
2 & 4	85	50	32	103	40.784	<0.001
3 & 4	67	68	32	103	18.437	<0.001
In Daylight - 450 ft. Visibility Fog						
1 & 2	49	5	38	16	5.911	0.015
1 & 3	49	5	33	21	11.398	<0.001
1 & 4	49	5	11	43	51.338	<0.001
2 & 3	38	16	33	21	0.658	-
2 & 4	38	16	11	43	25.254	<0.001
3 & 4	33	21	11	43	16.913	<0.001
In Darkness - Clear Weather - Urban Simulation						
1 & 2	70	65	58	77	1.797	-
1 & 3	70	65	48	87	6.639	0.010
1 & 4	70	65	27	108	28.382	<0.001
2 & 3	58	77	48	87	1.258	-
2 & 4	58	77	27	108	15.453	<0.001
3 & 4	48	87	27	108	7.385	0.007

Target No. 1: Standard 8" RR pair with 3 White strobes as per Figure D-3. Center strobe at 9 Joules. Outside strobes at 17 Joules.

Target No. 2: Standard 8" RR pair with 2 White strobes as per Figure D-7. Strobes at 110/min. and at 17 Joules.

Target No. 3: Standard 8" RR pair with single White strobe as per Figure D-4. Strobes at 220/min. and at 9 Joules.

Target No. 4: Standard 8" RR pair @ 55/min. and at 32 K fL.

1 inch = 2.5 cm
1 foot = .3 meters

9.0 RAILROAD GATE ARMS

Once again preliminary pilot tests were conducted with a few people to narrow the field of possibilities to six combinations of gate arms, lights and gadgets to be presented for test subject comparison.

The gate configurations were first narrowed to two types of reflectivity, two types of lighting and one kind of gadget that might increase conspicuity.

The gate configurations and flashing light timing sequences of all six gates tested are shown in Figures D-8 through D-13. All gates were presented with background clutter simulating an urban roadway environment. All decoys presented were positioned at the far left or far right. Opposing autos or headlights were the only competition seen in a position where a driver would expect only the roadway.

All displays were presented for 4-1/2 seconds at 420 feet.* Tests subjects noted the object that held their attention longest.

In each display, the gate arm configuration was scored yes, if the barricade, strobe light, or any other component of the configuration was noted. The frequency with which specific component parts of the gate arm configurations were noted by test subjects were as shown on Table D-41.

Tests in the fog were deleted from the experiment because the primary objects, the gate arms, were not visible at 420 feet* in fog.

9.1 Test Results

Based upon results in Table D-41, the following conclusions can be drawn.

1) The strobe lights provided the most collective enhancement to the gate arms.

2) The red strobe at the gate tip was not effective.

---

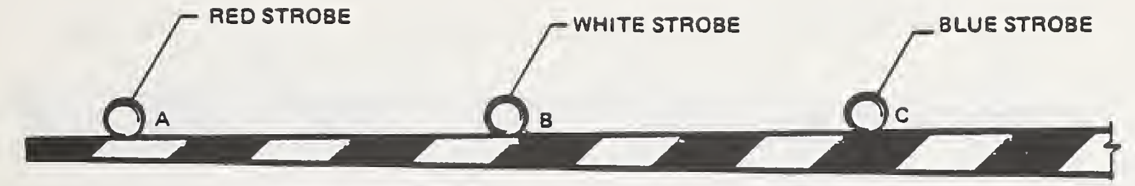
* 420 feet = 128.1 meters

TABLE D-41

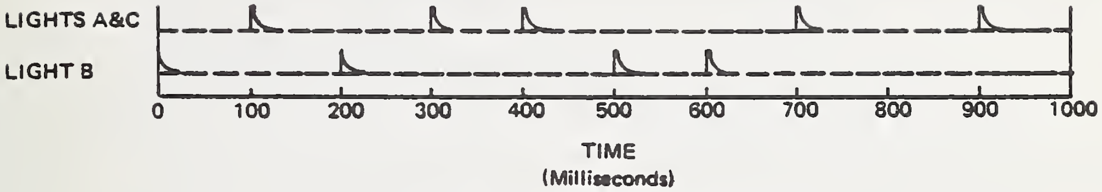
Gate Arm Component Part - Test Scores (Frequency That Each Component Was Noted By Test Subjects)

	Number of Times Noted by Test Subjects	
	Daytime	Nighttime
Arms With Retro-Reflectors	11	4
Arms With Reflective Sheeting	12	8
Incandescent Lights	5	2
Red Strobe	1	3
White Strobe	18	4
Blue Strobe	8	28
Strobe (no color identifier)	14	14
Stop Signs	14	9

NOTE: In scoring the gate arm tests, a given gate was scored as being seen if any component of the gate was noted on the test subject form. Highly competitive decoy targets were conjunctively shown with each display containing one (of six) gate arm configuration.

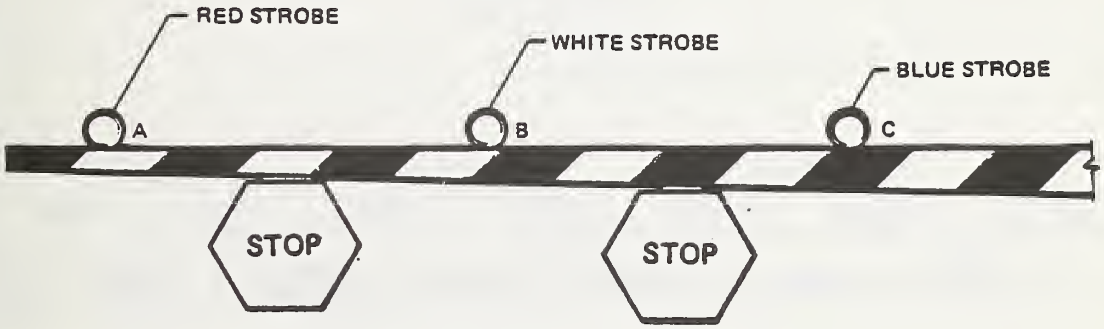


RED & WHITE REFLECTIVE SHEETING GATE ARM

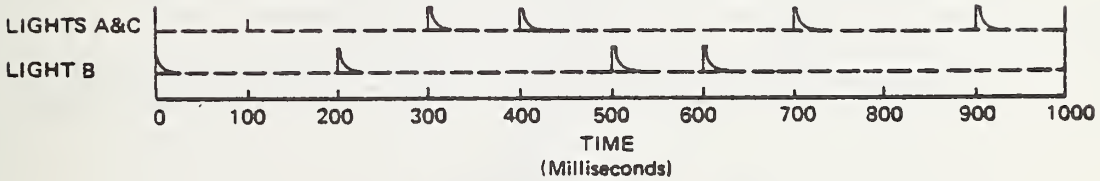


STROBE LIGHT FLASH SEQUENCES
(All strobes flash at 9 joules)

FIGURE D-8
GATE #1



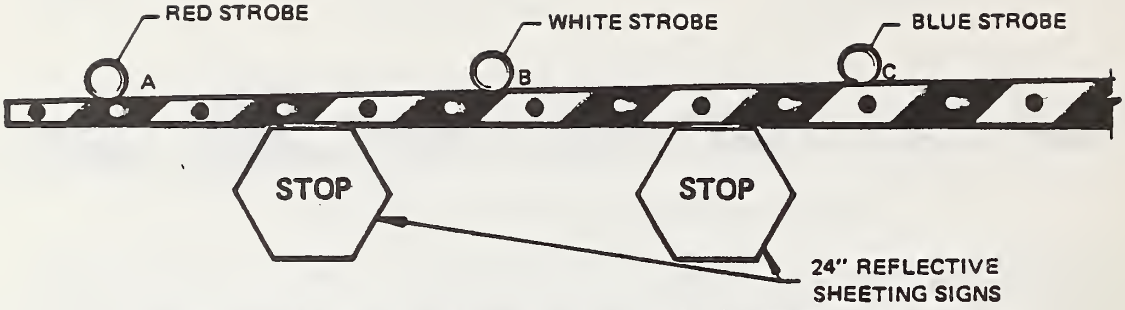
RED & WHITE REFLECTIVE SHEETING GATE ARM WITH
RED & WHITE REFLECTIVE SHEETING 24" STOP SIGNS



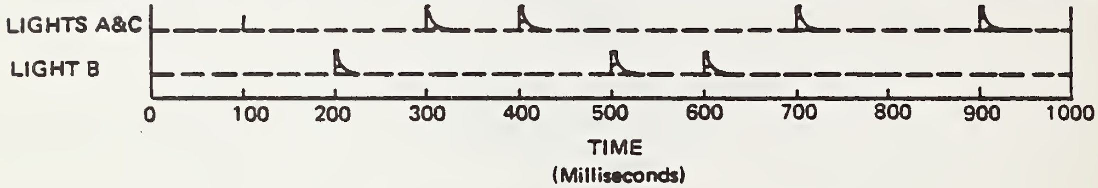
STROBE LIGHT FLASH SEQUENCES
(All strobes flash at 9 joules)

FIGURE D-9
GATE #2

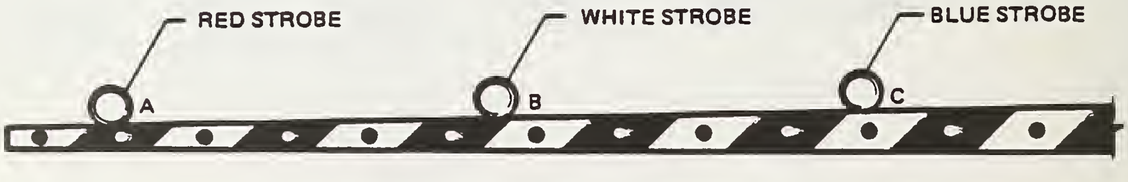
* 24 inches = .61 cm



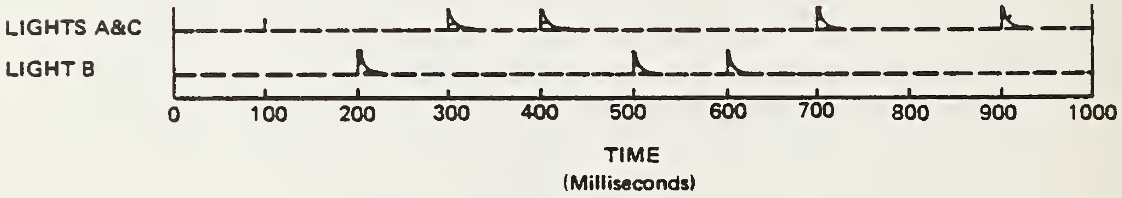
RED & WHITE PAINTED GATE ARM WITH 3" DIAMETER RETRO-REFLECTORS
RED REFLECTOR ON WHITE BACKGROUND – CLEAR REFLECTOR ON RED BACKGROUND



STROBE LIGHT FLASH SEQUENCES
(All strobes flash at 9 joules)
FIGURE D-10
GATE #3

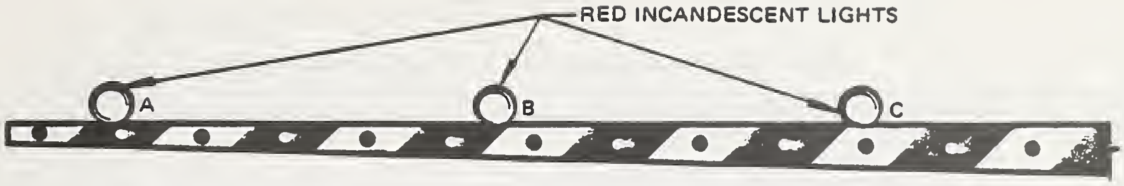


RED & WHITE PAINTED GATE ARM WITH 3" DIAMETER RETRO-REFLECTORS
RED REFLECTOR ON WHITE BACKGROUND – CLEAR REFLECTOR ON RED BACKGROUND



24 inches = 61 cm
3 inches = 7.6 cm

STROBE LIGHT FLASH SEQUENCES
(All strobes flash at 9 joules)
FIGURE D-11
GATE #4



RED & WHITE PAINTED GATE ARM WITH 3" DIAMETER RETRO-REFLECTORS
RED REFLECTOR ON WHITE BACKGROUND – CLEAR REFLECTOR ON RED BACKGROUND

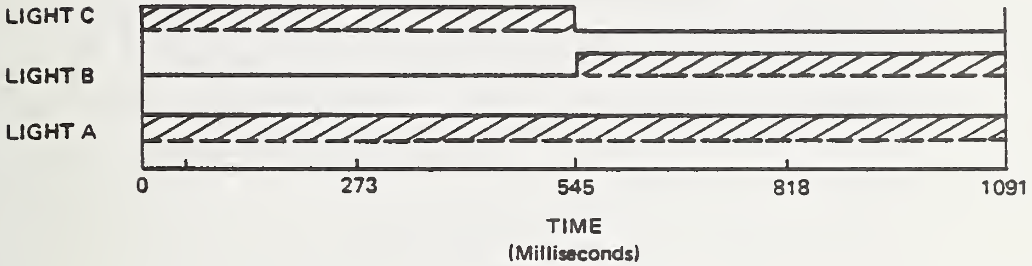
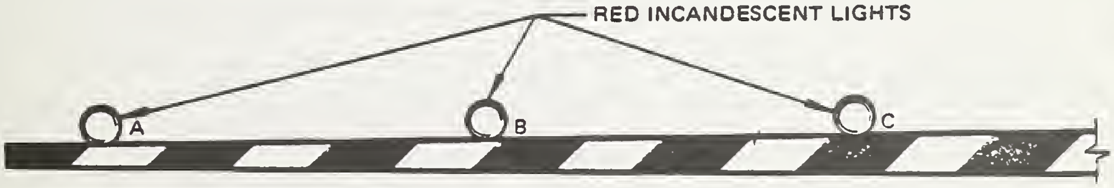
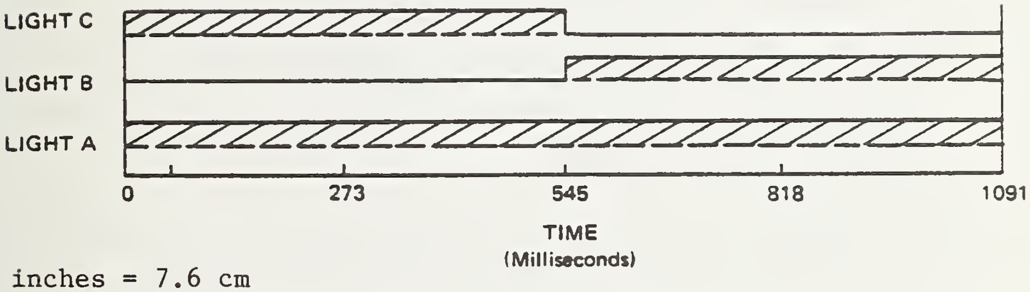


FIGURE D-12
GATE #5



RED & WHITE REFLECTIVE SHEETING GATE ARM



3 inches = 7.6 cm

FIGURE D-13
GATE #6

3) One white and one blue strobe replacing the standard flashing red incandescent lights should perform as well as the three strobe configuration used in the test.

4) The white strobe was most effective in daylight.

5) The blue strobe scored higher than the white strobe at night, however, it is strongly suspected that this happened because the white strobe appeared somewhat blue at night. It is hypothesized that some test subjects noted "blue" when it was actually the white strobe that gained their attention. Test monitors and observers had difficulty distinguishing white and blue strobes at night.

Test scores for the six gate combinations are shown in Table D-42 with the pair-wise statistical comparison results shown in Table D-43. Results are completely consistent between daytime and nighttime, however, the following conclusions are made relative to the compiled subject selection data:

1) Strobes (white and blue) add the most to gate are conspicuity.

2) Retro-reflectors (3"* diameter reflectors) are more important at night (unfortunately, reflective sheeting and retro-reflectors did not occur together in any target).

3) Stop signs seem more important than retro-reflectors in the daytime with nighttime results indicating a "draw" in terms of relative importance, however, stop signs present a possible problem in a raised gate arm position (non-active crossing warning system).

---

* 3 inches = 7.6 cm

TABLE D-42

Gate Arm Group - Test Scores

#	Gate Arms	Daylight - Clear			Nighttime - Clear		
		Sample Size	Yes	% Yes	Sample Size	Yes	% Yes
1	Ref. Sheeting With Strobes (Fig. D-8)	90	21	23	90	16	18
2	Ref. Sheeting With Strobes and Stop Signs (Fig. D-9)	90	20	22	90	16	18
3	Paint and Retros With Strobes and Stop Signs (Fig. D-10)	90	18	20	90	20	22
4	Paint and Retros With Strobes (Fig. D-11)	90	15	17	90	14	16
5	Paint and Retros With Incandescents (Fig. D-12)	90	4	4	90	3	3
6	Ref. Sheeting With Incandescents (Fig. D-13)	90	1	1	90	5	6

NOTE:

Gates #1, #2, #3, and #4 all used red, white, and blue strobes on the gate configurations. In each test session, of nine test subjects each, with four gate configurations using strobes, there were 360 (90 x 4 = 360) opportunities for these gate configurations to be chosen.

TABLE D-43

Gate Arm Group - Statistical Analysis

Comparing Pairs of Gate Arms	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Daylight - Clear Weather - Urban simulation						
1 & 2	21	69	20	70	0.000	-
1 & 3	21	69	18	72	0.131	-
1 & 4	21	69	15	75	0.868	-
1 & 5	21	69	4	86	11.892	<0.001
1 & 6	21	69	1	89	18.694	<0.001
2 & 3	20	70	18	72	0.033	-
2 & 4	20	70	15	75	0.567	-
2 & 5	20	70	4	86	10.817	0.001
2 & 6	20	70	1	89	17.466	<0.001
3 & 4	18	72	15	75	0.148	-
3 & 5	18	72	4	86	8.751	0.003
3 & 6	18	72	1	89	15.064	<0.001
4 & 5	15	75	4	86	5.884	0.015
4 & 6	15	75	1	89	11.593	<0.001
5 & 6	4	86	1	89	0.823	-

Target No. 1:	Reflective Sheeting with Strobes (Figure D-8).
Target No. 2:	Reflective Sheeting with Strobes and Stop Sign (Figure D-9).
Target No. 3:	Paint and Retro Reflectors with Strobes and Stop Signs (Figure D-10).
Target No. 4:	Paint and Retro Reflectors with Strobes (Figure D-11)
Target No. 5:	Paint and Retro Reflectors with Incandescents (Figure D-12).
Target No. 6:	Reflective Sheeting with Incandescents (Figure D-13).

TABLE D-43 Continued

When Comparing Devices	2 x 2 Contingency Table				χ^2	When $\chi^2 \geq 2.70$ Difference is Significant at Level
	a	b	c	d		
	Yes	No	Yes	No		
In Darkness - Clear Weather - Urban Simulation						
1 & 2	16	74	16	74	0.038	-
1 & 3	16	74	20	70	0.313	-
1 & 4	16	74	14	76	0.040	-
1 & 5	16	74	3	87	8.473	0.004
1 & 6	16	74	5	85	5.391	0.020
2 & 3	16	74	20	70	0.313	-
2 & 4	16	74	14	76	0.040	-
2 & 5	16	74	3	87	8.473	0.004
2 & 6	16	74	5	85	5.391	0.020
3 & 4	20	70	14	76	0.907	
3 & 5	20	70	3	87	12.761	<0.001
3 & 6	20	70	5	85	9.105	0.003
4 & 5	14	76	3	87	6.496	0.011
4 & 6	14	76	5	85	3.766	0.052
5 & 6	3	87	5	85	0.131	-

Target No. 1:	Reflective Sheeting with Strobes (Figures D-8).
Target No. 2:	Reflective Sheeting with Strobes and Stop Sign (Figure D-9).
Target No. 3:	Paint and Retro Reflectors with Strobes and Stop Signs (Figure D-10).
Target No. 4:	Paint and Retro Reflectors with Strobes (Figure D-11).
Target No. 5:	Paint and Retro Reflectors with Incandescents (Figure D-12).
Target No. 6:	Reflective Sheeting with Incandescents (Figure D-13).

REFERENCES

APPENDIX D

1. Pudinski, W., Blue Lights - California Reports, Police Chief, Vol. 15, No. 11, 1973.

2. Cole, B. L., Visual Aspects of Road Engineering, Proceedings, Australian Road Research Board, Vol. 6, Part 1, 1972, 102-148.

3. Gerathewohl, S. J., Conspicuity of Flashing Light Signals of Different Frequency and Duration, Journal of Experimental Psychology, Vol. 48, No. 4, 1954, 247-251.

GLOSSARY

balanced experimental design — When, during a complete test session, each primary target was presented exactly the same number of times, in exactly the same position, and with precisely the same competitive devices to negate the bias that may result from some test subjects' tendency to favor a particular position, color, sign, height, luminance, size, flashrate, etc.

brightness — The subjective visual sensation produced by observing an illuminated surface.

cabin — Moving test subject presentation cabin. The moving enclosure that housed the test subjects during all display presentations.

candela — A standard light source which emits 4π lumens. A candela has an intensity of 1 candlepower.

conspicuity, conspicuousness — The ability to attract and/or maintain one's attention.

daylight fog — Artificial fog that provides visibility of no less than 450 feet* and no more than 500 feet*, as discussed on page 4-3.

decoy — A target designed to lead test subject's attention away from the primary target.

display — An array of targets presented to test subjects for comparing conspicuity. A display usually included three targets.

foot-Lambert — $1/\pi$ candela per square foot.* A unit of luminance.

illuminance — The luminous flux falling on a surface. The typical unit is the foot-candle and is equal to the illumination falling on a surface 1 foot* from a 1-candlepower source.

lumen — The standard unit of flux.

luminance — The luminous intensity per unit of surface area of the angle of flow. A typical unit of luminance might be candela per square inch* or foot-Lambert.

* 450 feet = 137.3 meters
500 feet = 152.5 meters
1 square foot = .09 sq. meters
1 foot = .3 meters
1 square inch = 6.5 cm^2

luminous flux — The time rate of flow of light indicates the intensity of the source.

no — The number of times a primary target was not chosen by test subjects.

primary target — Those targets being directly compared with each other during a test session.

radiance — Radiant flux radiated per unit solid angle and unit projected area of source.

radiant energy — Energy traveling through space in the form of electromagnetic waves of various lengths.

radiant flux — The time rate of transfer of radiant energy.

radiant intensity — Radiant flux radiated per unit solid angle about a source.

rural simulation — High contrast, neutral background as might be found on a lonely rural road.

sample size — The number of opportunities for a primary target to be chosen by test subjects during a test session, i.e., the number of times presented multiplied by the number of test subjects.

significant — Sufficient statistical evidence to support a conclusion, as discussed in Appendix C.

standard — The structure supporting a light device and/or a roadway sign. The lights were usually mounted 7 feet* high. Signs were hung below the lights.

target — A standard with flashing lights and/or a sign. Three targets were usually included in each display.

urban simulation — Low contrast background with people, roadside signs, roadside lighting, buildings, windows, opposing automobiles, and opposing headlights to be seen in competition with test displays.

yes — The number of times a primary target was chosen by test subjects.

* 7 feet = 2.1 meters

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

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1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

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Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

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