150

SIGNAL SIZE IN APPARENT DETECTABILITY OF RAILROAD - HIGHWAY CROSSING SIGNALS

by

PADMANABHAN RAMANKUTTY

B.E(Production), Government College of Technology,

Coimbatore, India. 1981.

A MASTER'S THESIS

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas.

1983

Approved by:

Major Professor

THIS BOOK CONTAINS NUMEROUS PAGES WITH THE ORIGINAL PRINTING BEING SKEWED DIFFERENTLY FROM THE TOP OF THE PAGE TO THE BOTTOM.

THIS IS AS RECEIVED FROM THE CUSTOMER.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation and gratitude to Dr.Corwin.A.Bennett for his valuable guidance and encouragement throughout his study in this university.

The author is indebted to Professor Jacob.J.Smaltz and Dr.Bob.L.Smith for serving on the graduate committee. The author wishes to thank Dr.J.Higgins and Mr.Anjo Thoppil for helping with the statistical analysis of data.

The author is indebted to Pradeep Sethia for the numerous occasions he has helped during the course of the author's study in Kansas State. The author is grateful to all his friends who have helped him in this research.

The author will be failing in his duty if does not thank Mr.Richard Plinsky And Allard Inc for lending the equipment. The author is thankful to them.

Last but not certainly the least, the author is indebted to his parents without whose encouragement and support this graduate program may not have materialized. It is to them that this work is dedicated.

LIST OF TABLES

Page

LIST OF FIGURES

Page

INTRODUCTION

The basic train activated flashing lights now found at many railroad-highway grade crossings, either alone or in conjunction with automatic gates and bells, have been in use for more than fifty years. In the United States there are nearly 54,840 public railroad-highway crossings with active warning devices. The Department of Transportation's Office of Safety states that this represents about 25 percent of all public railroad-highway crossings. About 56 percent of the accidents that occurred on railroad-highway grade crossings with active warning devices were reported as the motorist "Did Not Stop". The large number of accidents is due to the increase of train and motor vehicle traffic. The reason for not stopping is not precisely known but may be due to the fact that the driver did not detect the warning signal or detected it too late.

Railroad-Highway Grade Crossing Signals

The railroad-highway grade crossing signals and the traffic signals began to evolve in the late 19th century. The earliest railroad-highway crossings consisted of signs bearing legends. The engineer of the train had to blow the locomotive whistle when approaching a crossing. Soon when rail traffic increased, came the flagmen who waved a red flag during the day and a lantern at night to warn people and carriages of the approach of a train.

Brigano and McCollough(1981) and Fisher(1951) state that the L.S.Brach patented signal was the first flashing light signal. It consisted of eight lights arranged as the lower arc of a circle, mounted on a similarly shaped background. The signal head was mounted on a metal mast with the legend "RAILROAD CROSSING" in large letters above it. It was apparently the first signal in which the lights were lighted sequentially, back and forth to simulate the flagman's swinging lantern. Other flashing signals were developed during the early 1900's and the current signal configuration was developed in 1920 (Figure 1).

The post mounted railroad-highway crossing signal has remained the same over the years. The signal consists of two incandescent lamps mounted in housings, reflectors behind red lenses(roundels). The lamps are aligned horizontally at a spacing of 30 inches(76.2cm) against a 20 inch(50.8cm) circular black background. They are flashed alternately at a rate of 35 to 55 flashes per minute. The proceedings of the 30th annual convention of the American Railway Engineering Association(1929) states that a 5 3/8 inch diameter signal was considered minimum and 8 3/8 inch diameter signal was considered as maximum. The Ad-Hoc

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

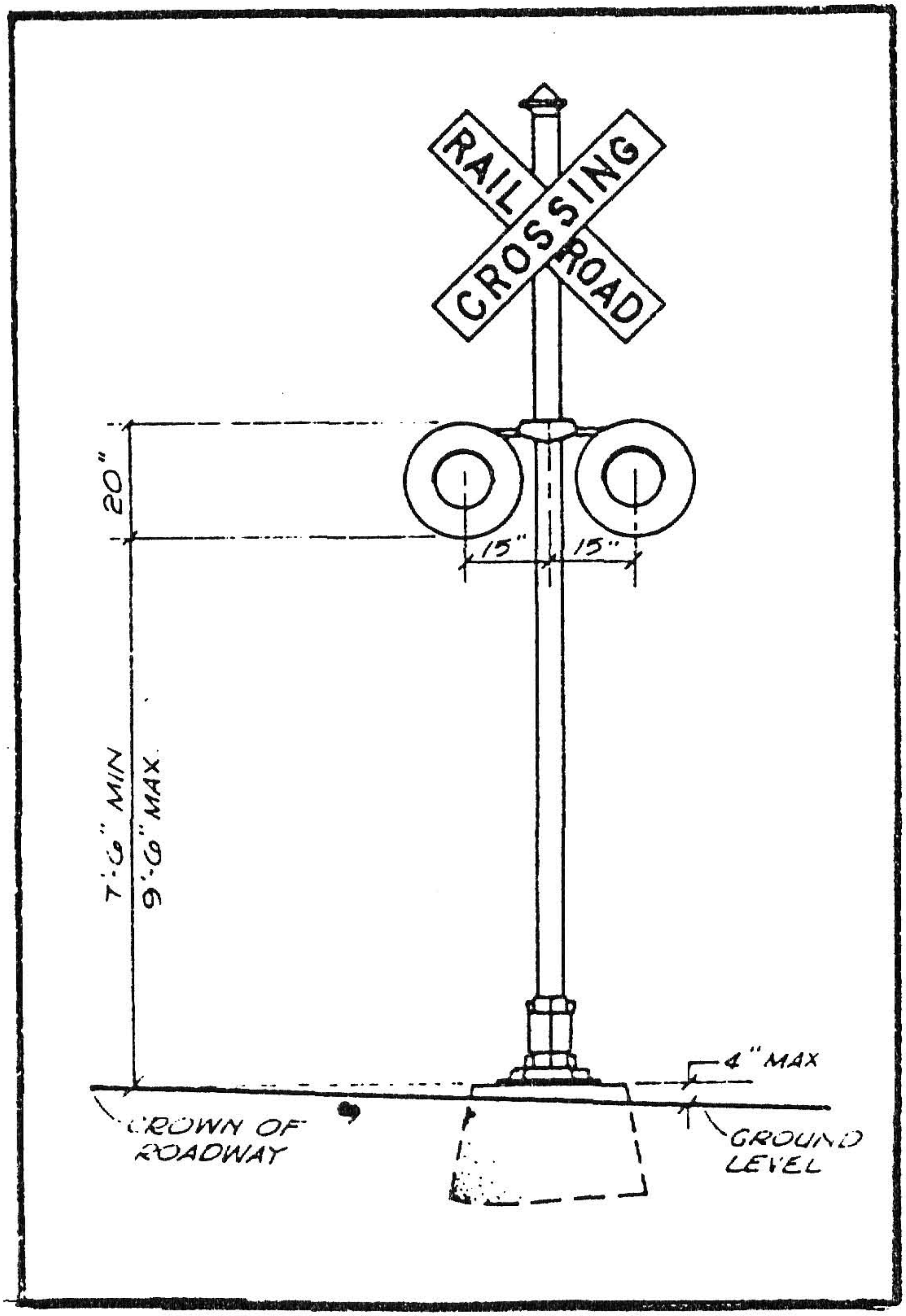

Figure 1. Grade Crossing Signal

committee D of the Association of American Railways (AAR) during 1966-1968 developed comparative data on the 8 3/8 inch flashing light and the 12 inch(30.5) traffic signal. Ever since, 12 inch(30.5cm) signals have been included in the signal manual as an option and are in widespread use today.

Grade crossing signals are commonly mounted on masts about 9 feet(2.7m) above the road and about 15 feet(4.5m) to the side of the motorist lane centerline or on a cantilever about 18 feet above the driver's track.

Cole and Brown(1966) calculated the angles between the driver's horizontal line of sight and the signals show the vertical angles for the mast mounted signal to be 1.03 degrees and 0.45 degree at 300 feet and 700 feet respectively, and for the cantilevered signals to be 2.8 degrees and 1.2 degrees at these distances. The two distances are the safe stopping distances for vehicles approaching the crossings at 30 mph and 60 mph. Any change in the approach road like a curve or a grade will increase or decrease the angle.

There are essentially nine parts of a railroad -highway crossing signal that, when combined, create the light seen by the motorist. These parts are a light source, reflector, light source holder, lens or roundel, power source, a housing, mechanical adjustments to align the entire fixture and electrical support equipment to cause the signal to change states(Figure 2 and Figure 3).

The light source for the railroad-highway crossing signal is typically provided by a 18 or a 25 watt cc6 filament incandescent bulb operating on a rated 10 volt system. Most of the light sources emit light in most directions. Since the purpose of the signal is to present a warning in a specific direction and usually in a particular area. A reflector is necessary to collimate the light so the output can be directed. This is accomplished with parabolic mirrors made of plastic, polycarbonate, glass or aluminium. The reflecting quality of the mirror is produced by either coating the inside surface with reflective material, polishing the surface or coating the backside.

Bulb adjustments in railroad-highway crossing signals have provisions to allow the source to be moved in all three axes. These adjustments are very critical because they affect the focusing problem. Movement of the bulb filament in increments as small as 1/8 inch(3.2mm) can decrease the output of a light by as much as 75 %.

A roundel is defined as a cover placed in front of the reflector and lamp for the purpose of producing a colored light of a specific pattern and lens is a cover which magnifies the light source. The roundel performs the functions of coloring and directing the light to the approaching motorist.

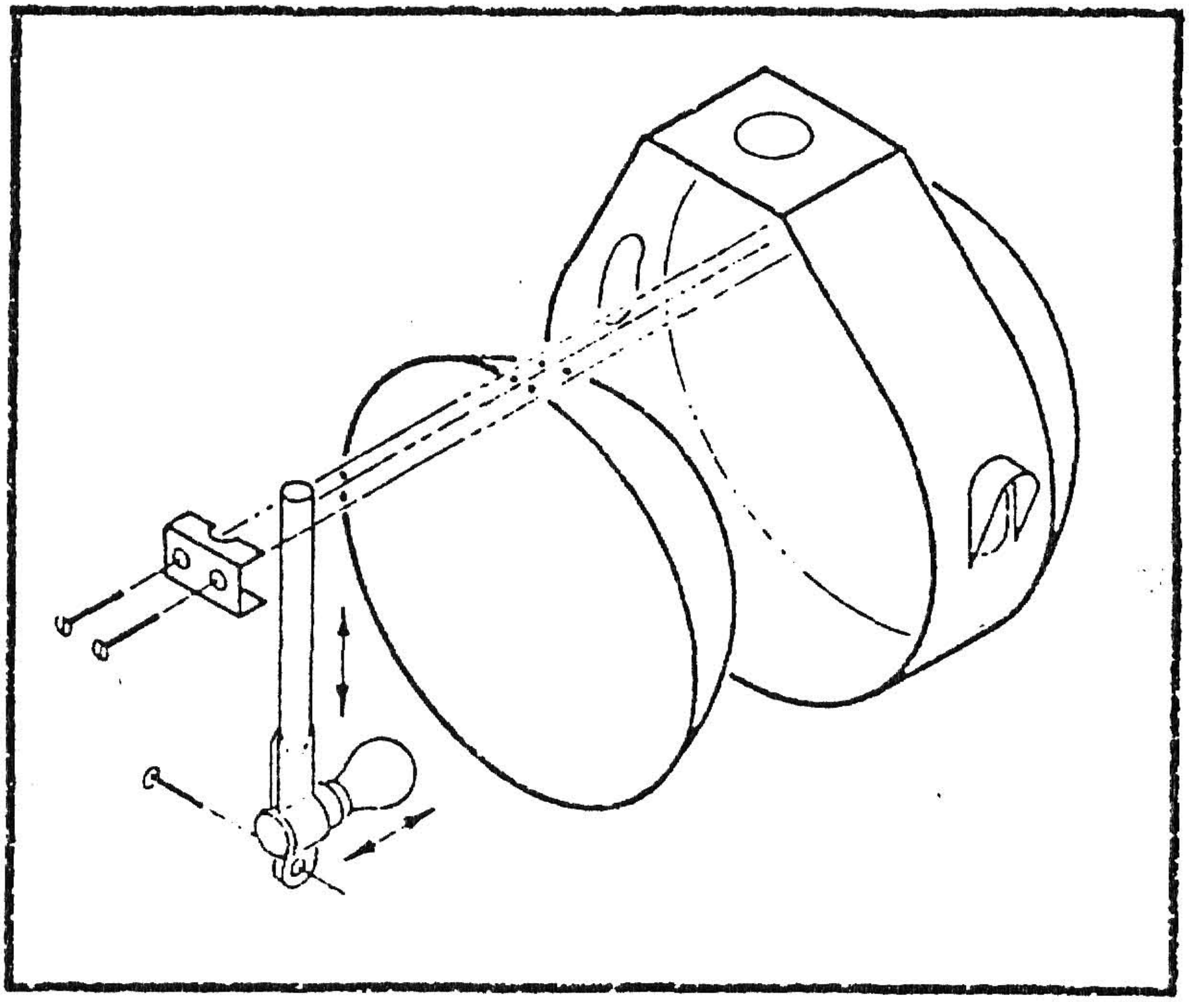

Figure 2. Flashing Light Unit

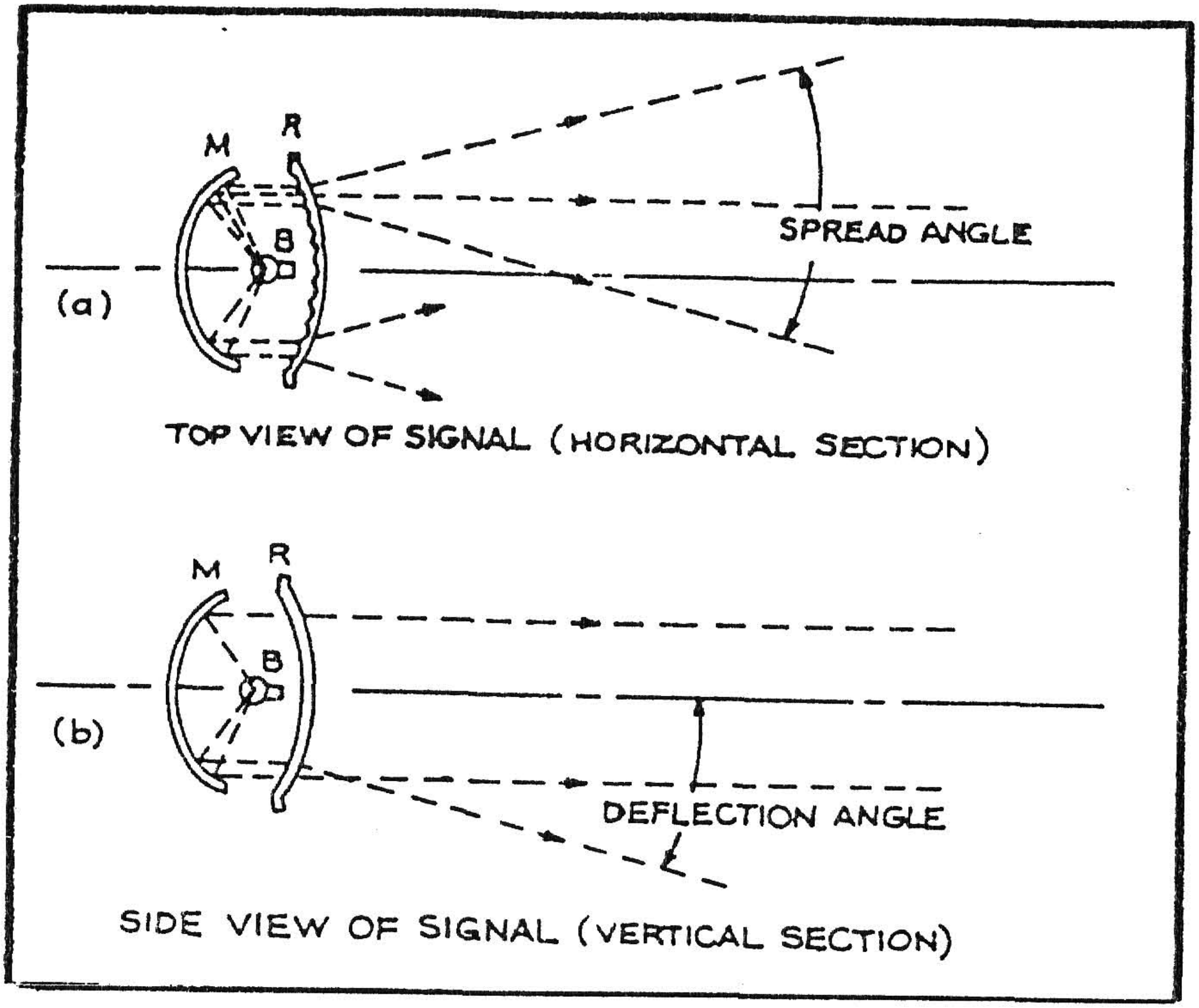

Figure 3. Typical Crossing Signal Roundel

The wattage, voltage of the railroad-highway crossing signals operate on a 10 volt system. So if commercial power is not available, the signal is off and the motorist thinks it is safe to cross the tracks, when it might not be so. To avoid such situations a battery backup is provided.

Section 4B-11 of the Manual on Uniform Traffic Control Devices Standard (MUTCD,1971) states regarding aligning procedures, 'In general, vehicular signal faces should be aimed to have effectiveness for an approaching driver located at a distance from the stop line equal to the distance traversed while stopping. This distance should include that covered while reacting to the signal as well as that covered while bringing the vehicle to a stop from an average approach speed. The influence of curves, grades and obstructions should be considered in directing and locating signals'.

Human Factors Requirements

Human visual capabilities are essential to understand in that it is the human eye that initiates the action to stop the motor vehicle at the grade crossing. The interpretive abilities of the brain are not concerned, but the eye's capability to detect a signal is what counts on the human factors aspect. The capabilities that intiate the action include intensity sensitivity, color perception and contrast perception and are affected by sight height, viewing angle and limitations imposed by the vehicle.

Cunagin and Abrahamson(1975) found that the average driver's eye height has dropped from 4.6 feet in 1930 to 3.6 feet in 1979. This means that the position of the post mounted signal is about 5.5 feet above the average driver's eyes and 15 feet to the side, while the cantilevered signal would be 14.5 feet and lies along his track.

Signal Light Intensity and Eccentricity

The amount of light emitted by the signal is expressed as intensity, sometimes called candlepower and is measured in candelas. Cole and Brown (1966,1968) carried out experiments in simulated conditions in which they studied reaction time as a function of light intensity, distance, background luminance and signal size.

Cole and Brown(1968) developed a 200 candelas criterion for motorists warning signals under stringent conditions. These conditions were observations made at 100m and against a high background luminance. The observers were also viewing the light from a position directly in front of the light. An intensity threshold of 200 candelas was the minimum required for daytime driving according to their conclusion. Many researchers after Cole and Brown have also validated the 200 candelas criterion. Hulscher(1974) presented the graph in Figure 4, which shows that 200 candelas is needed at 300 feet. Since the driver should detect the signal before 300 feet, this should be considered a minimum intensity for daytime driving. For night driving conditions the intensities would be effective because of the higher contrast.

Fisher and Cole(1974) state that as eccentricity of the signal increases from the driver's line of sight to 20 degrees, signal intensity has to be increased in order to be detectable. Hall and Greenbaum(1950) state that the maximum visual acuity or the clearest seeing takes place during any given time increment in a field of vision subtended by a cone with an angle of three degrees. When both eyes are looking forward perception can take place in a total central angle ranging from 120 degrees to 160 degrees(Figure 5). This vision is peripheral vision. Visual acuity is less in the peripheral vision. The signals are detected by peripheral vision and hence it is out of the maximum cone of sensitivity of vision. So the intensity of the signals have to be increased. Rudden and Wasser(1977) also suggest that signals located close and aligned to the roadway will be easier to detect.

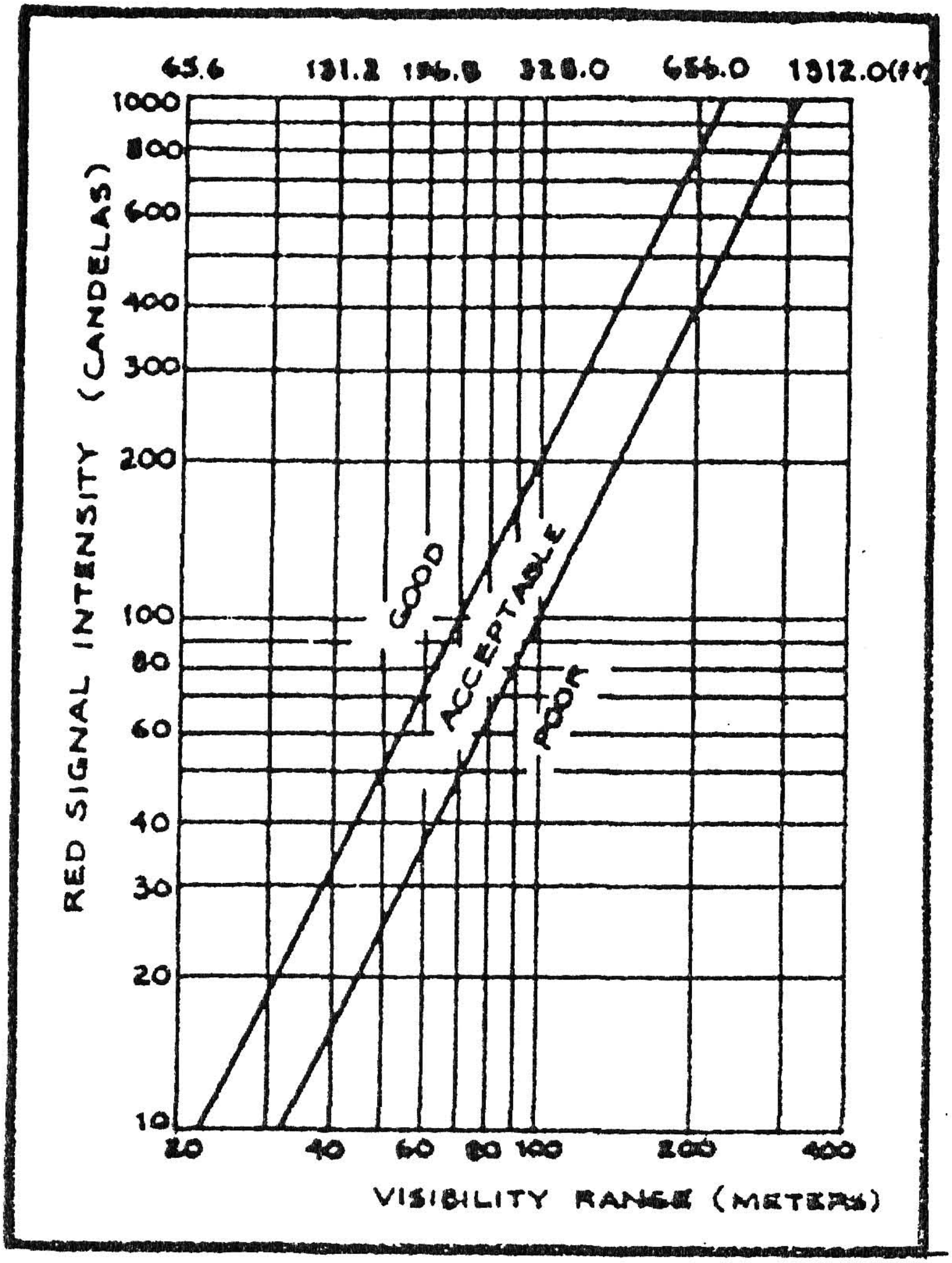

Figure 4. Variation of Red Signal Intensity with Signal Range

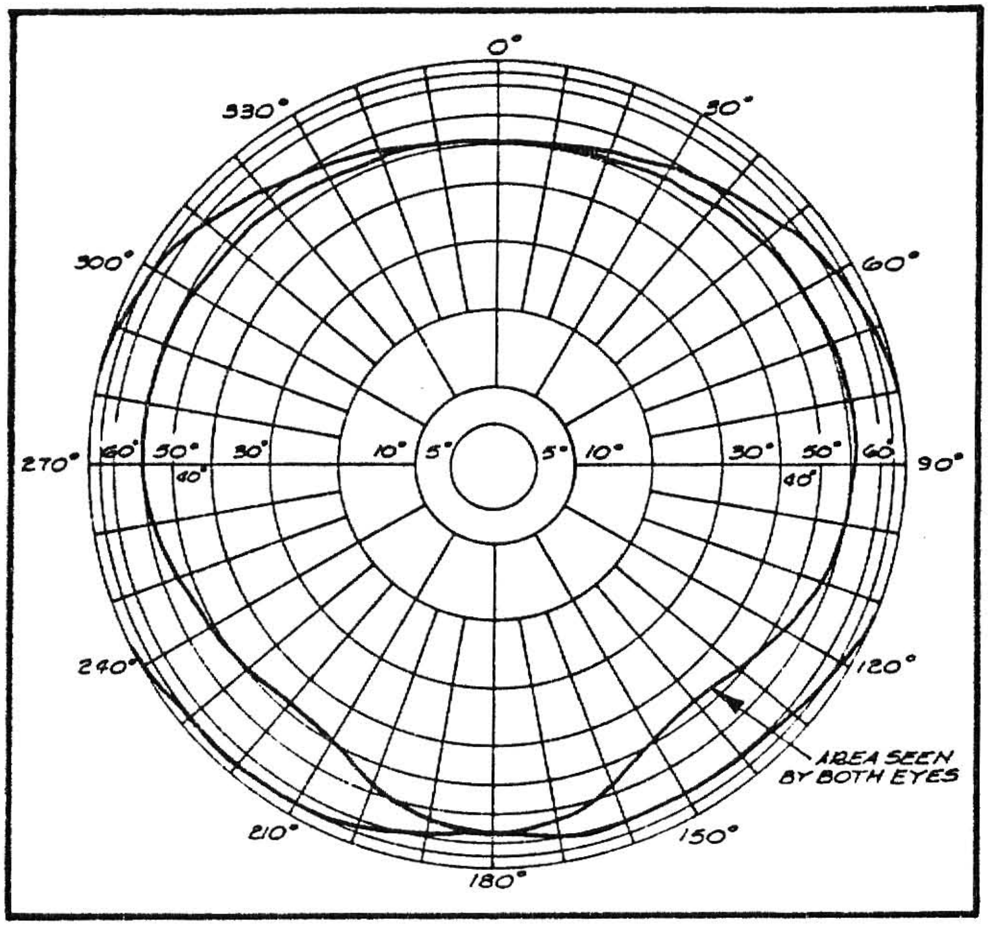

Figure 5. Field of View, Human Vision

Color and Contrast

Dunlap was calling for a more yellowish red signal light as early in 1928. The grade crossing light had been a "deep"red (higher wavelength) because it was desired that the signal to be recognized as red. However detectability is reduced by the extremeness of red. About two percent of drivers, mainly males have a type of color blindness which reduces their sensitivity to the more red wavelengths.

The luminosity curve(Figure 6) shows how the luminosity increases as the wavelength of the red is brought closer to the yellow wavelength. The "deep" railway red filters have very low transmissions(0.1 to 0.15) which reduces the light intensity. The CIE(International Commission on Illumination,1975) gives detailed specifications for reds on an absolute basis and can be discriminated from yellow. The CIE chromaticity diagram shows this(Figure 7). The boundaries of the recommended reds are $x=0.335$ $y=0.980-x$. Hopkins and White(1977) say that if the drivers have lost sensitivity to color and if the roundel has a "deep" red then it could result in failure to detect the signal.

Signal detection in the laboratory

This is a function of the contrast between the light and the simulated sky background. In actual practice a black background "target board" surrounds the signal. For a 8 inch signal, a 20 inch diameter circular surface is placed behind the signal. The practice of using black target

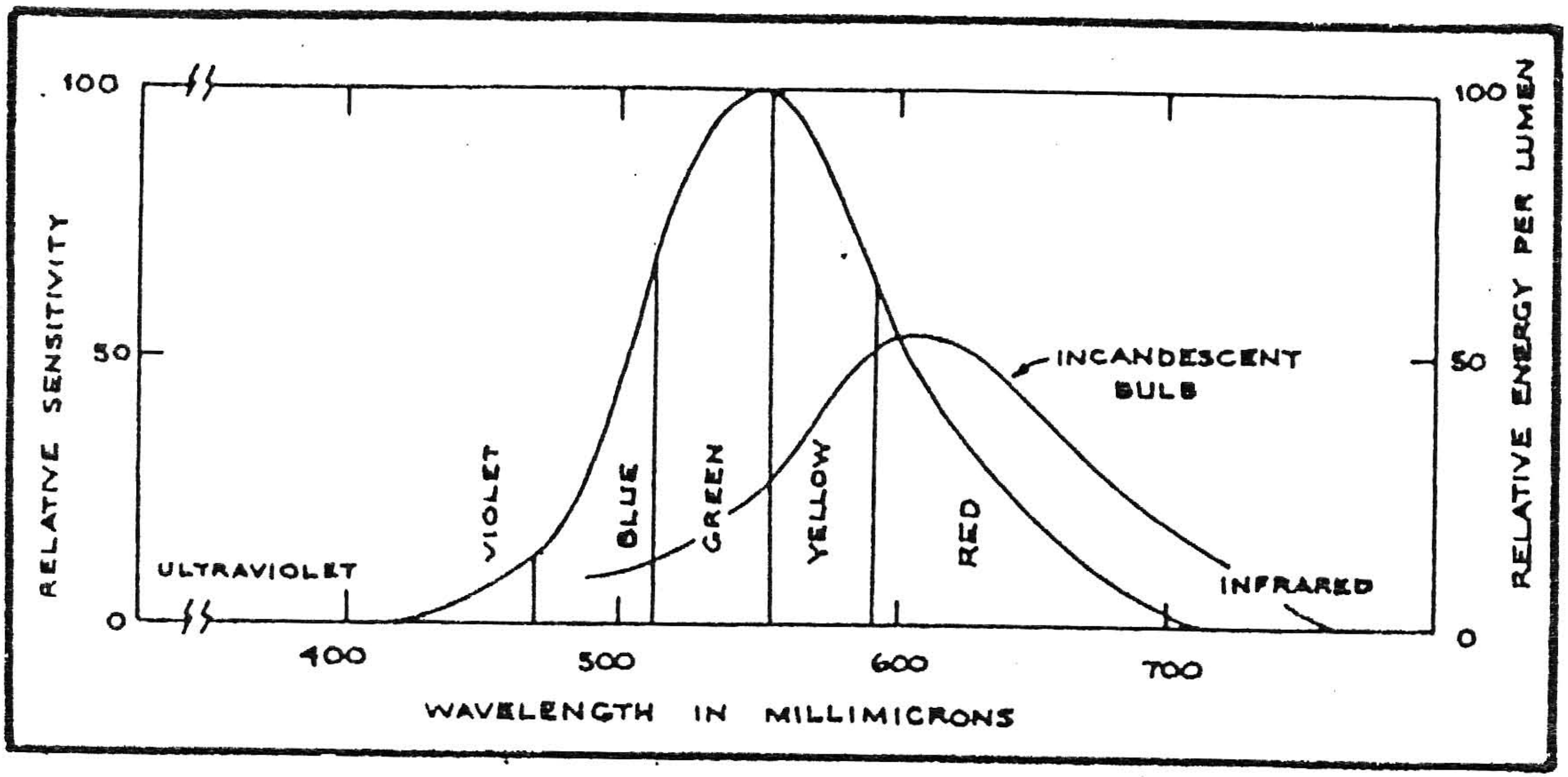

Figure 6. Luminosity Curve

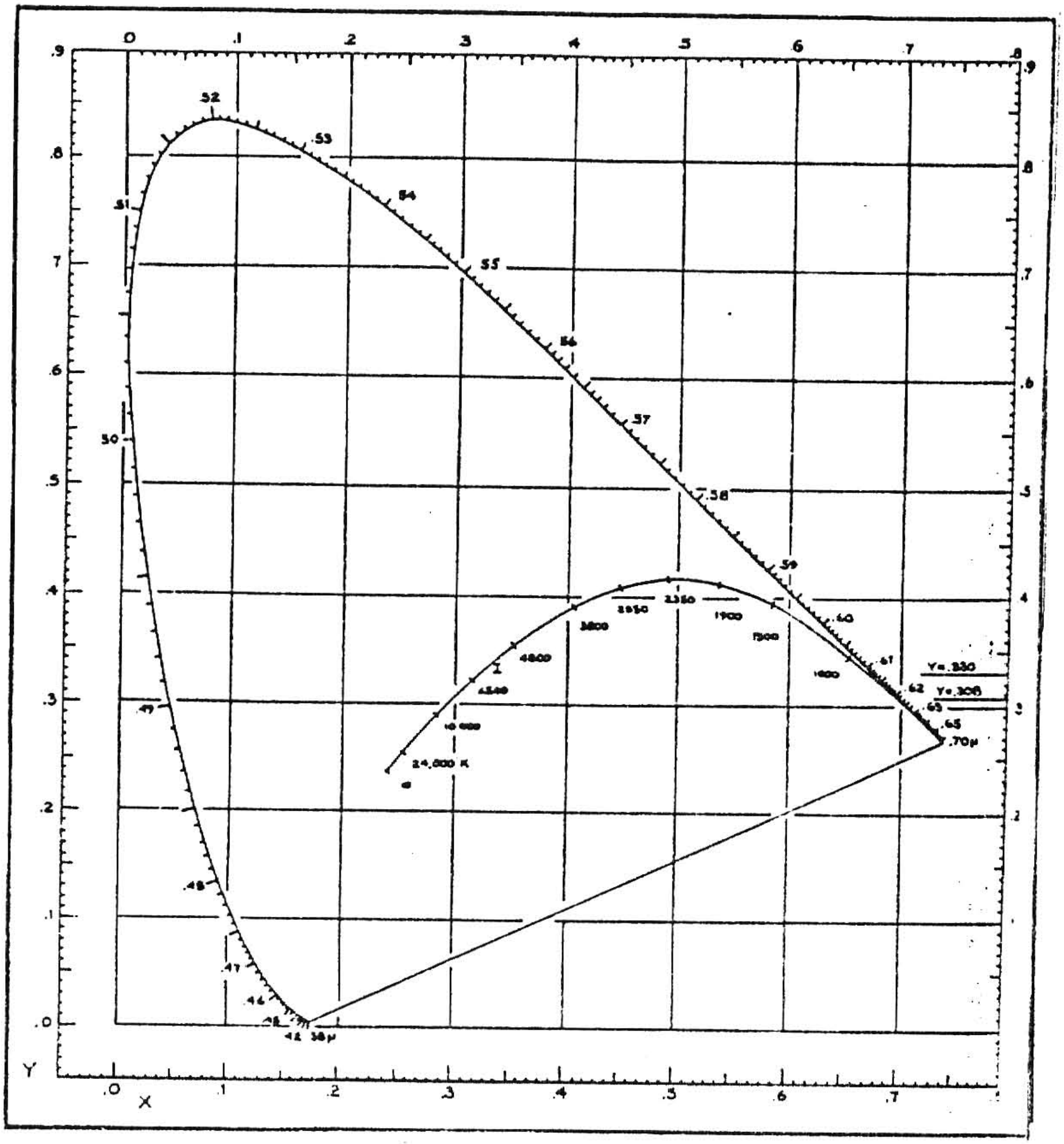

Figure 7. CIE Chromaticity Diagram

boards around signal lights to increase their conspicuity has been investigated by Cole and Brown(1966). They showed that as the screen size increases the signal intensity required is decreased.

Detectability of a Signal

Driving is a complex psycho-motor task incorporating a three stage process of perception, decision and implementation. Factors influencing the perception of a signal light have been simulated and have been systematicallly studied by Cole and Brown(1966,1968), Fisher and Cole (1974), Mashour(1974) and Rudden and Wasser(1977).

Fisher and Cole(1974) commenting on perception of signals state that the probability of detecting a light stimulus depends on its intensity. At low intensity it will be seen only occasionally, but as the intensity is increased the probability of seeing increases sharply until it will be rarely missed. Not only does the probability of detection increase with increasing stimulus intensity, but reaction time decreases. Probability of detection and minimum reaction have been used in studying the photometric requirements of signals by Cole and Brown(1968) and Fisher (1969).

Size of Signal Light and Detectability

The CIE (International Commission on Illumination, 1980) observes that the more distant a signal is, the smaller will be the angle subtended by the signal at the driver's eye. It is known that in foveal vision it is possible to integrate light flux over only a small area of the retina of the eye; that is, the visual system has only a limited capacity for spatial summation. As a consequence, it might be expected that small lights would be more visible or detectable than larger lights of the same luminous intensity.

Masaki et al (1971) as reported in the CIE (1980) report, found that a small high luminance signal light is more effective than a large, low luminance signal light of the same luminous intensity. Cole and Brown (1968) in an investigation using a simulated car driving task, showed that the response of the observer depends only on the amount of light reaching the eye from the signal and is independent of the size of the signal from which the light has come. Subjects sat in a simulator, which was like driving a car along a stretch of road. The observer was asked to take his leg off a pedal as soon as he observed a red light. The reaction time was measured. If the reaction time was less than 2.7 seconds, the signal was regarded as having been seen. The signals appeared at irregular time intervals and a trial of 50 signals were shown to each subject.

Five signals varying in size from 4.75mm in diameter to 19mm in diameter were shown in a random order for each subject. The background luminance was maintained at 600 Ft-lamberts. Each signal size was shown at different positions at irregular time intervals.

These conclusions were based on the subject's reaction time being shorter than the time for response, which was 2.7 seconds. The reaction time reaches its minimum for lower luminances with large sized target (Figure 8) When those luminances are plotted against size there is a negative slope such that, if luminance is converted into intensity the dependence of detectability on size disappears.

Cole and Brown's study used a tracking task which caused the observer's line of sight to be deflected from the signal by five degrees. Fisher and Cole(1974) point out that when a motorist approaches a signal,the driver is not looking at the signal directly but sees it in his peripheral vision. Fisher and Cole(1974) concluded that the tracking task provided by the simulated study of Cole and Brown was a correct simulation of the real task and that it could assumed from their result that optimum intensity is independent of signal size.

King(1975) found 12 inch traffic signals better than 8 inch signals. He used 72 subjects (40 males and 32 females) to view three different kinds of signals. They were 8 inch signals with a 67 watt lamp and 12 inch signals with a 116

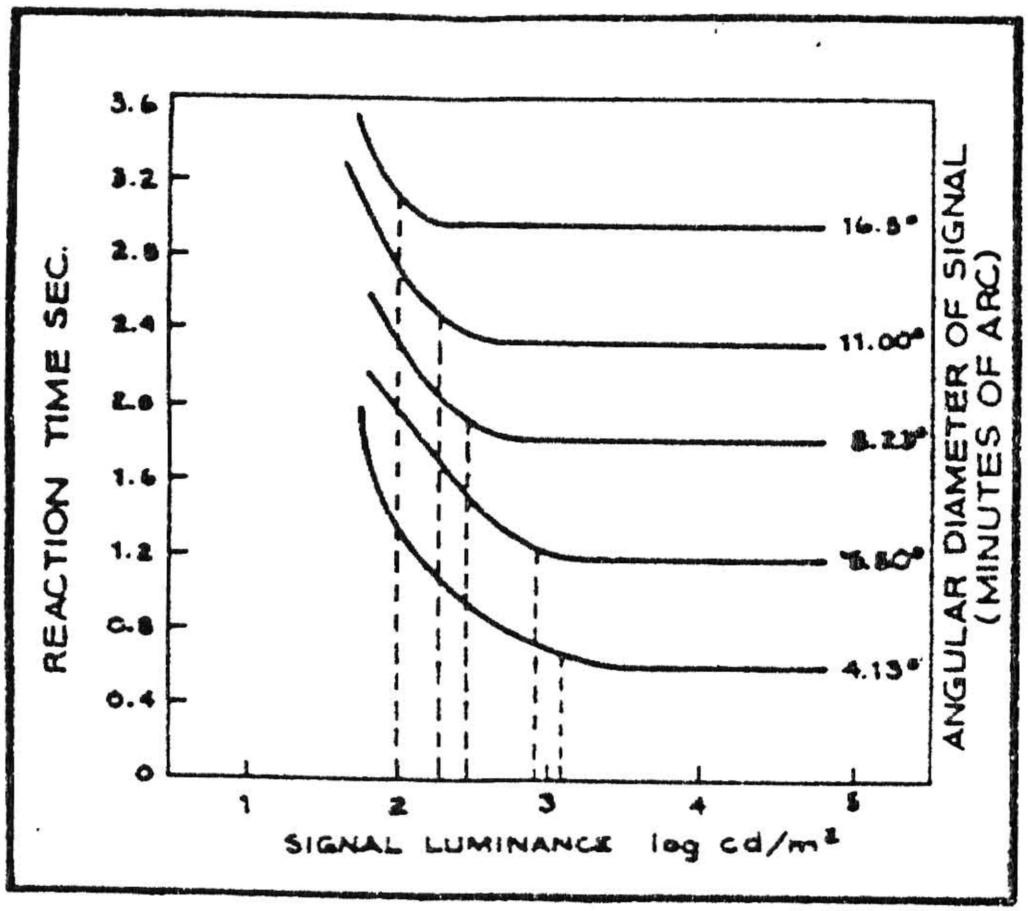

Figure 8. Signal Luminance versus Reaction Time

watt lamp or a 150 watt lamp. The subjects were asked to view the signals on a section of a freeway under day and night conditions. The subject's response when he saw a signal was to press a button, which was hooked to a microprocessor. The subjects were also asked to do a subsidiary task to bring in the effect of driving. Subjects were tested at various distances from the signals and their response time noted . An analysis on the subjects' response time was done. King concluded that the 8 inch signal was above the threshold level of visibility for night time driving. His test results showed that the 12 inch signal with the 150 watt lamp was significantly different from the 8 inch signal with the 67 watt lamp and that the 12 inch signal with the 116 watt lamp was not significantly different from the other signal. King used signal type as a variable in his analysis and not signal size.

Rudden and Wasser(1977), in different experiments, either controlled luminance or intensity for 8 inch and 12 inch signals. With the same luminance 12 inch signals were found to be better, however with constant intensity there is no significant superiority of the larger signals. They concluded that larger signals can made better by increasing the intensity ,which would require greater power usage.

Mashour(1974) used 40 subjects in an experiment to detect signals while performing a tracking task. The tracking task consisted of keeping a target in the middle of the track on the screen of a simulator. The subjects were given three minutes to learn the task. Each subject was shown 13 signals in a random order. They were asked to press a response button as soon as they saw that a signal was on. The data collected were the subject's detection time(response time) and the number of tracking errors. The detection time was analyzed and found that there were variations when signals were presented in the most peripheral position. Detection time varied between signals and varied for the same signal in different positions. The signals were then rank ordered on the basis of detection rate, which is the reciprocal of detection time. Mashour concludes that the differences in degree of detectability between signals are due to the contrast, the source intensity(luminance x area) and change in contrast.

Mashour(1974) states that subjective judgment of signal detectability is a related problem in signal detection. He used 202 subjects to subjectively judge 20 signal configurations. These signal configurations were painted in color and arranged in four series on a sheet of paper. The subjects were asked to rank order them. On analysis it was found there were individual differences in the judgments. Comparing the judgments to the rank order done on the detection rate, it was found that they did not match.

Subjective evaluation of signal detectability as compared to signal size should be done to find out whether humans feel that size is a factor in the detectability of a signal. A study was done by the author in April 1983. The experiment was conducted to find the judged detectability of 12 inch diameter railroad -highway grade crossing signals. Eighteen subjects were asked to examine nine different signal combinations (three signal housings and three roundels). They were asked to rate each of the nine signals shown on a scale of 1 to 20 and on the basis of the signal shown first, which they were told had a rating of 10 on detectability. This signal was shown in the end of the trial by the experimentor.

The signals were kept at a distance of 275 feet and subjects were shown signals in a random order. They were then asked to rate on the detectability of the signals. A statistical analysis on the ratings showed a significant difference among the treatments, which were the signal combinations. An analysis of variance showed that subjects preferred "deep" dish reflector signals with a "20-32" roundel. The luminance measures in the laboratory matched the subjective evaluations.

PROBLEM

The problem is to determine whether signal size affects judged detectability of railroad-highway crossing signals. Cole and Brown(1968) stated that size is independent of detectability but they used only reaction time to come to this conclusion. Rudden and Wasser(1977) stated that the 12 inch diameter signals were better when compared with an 8 inch signal having the same luminance. With constant intensity they found that the 12 inch signals were not superior. They also used reaction time in their study.

This study examined the signal size effect on the apparent signal detectability using human subjects to evaluate the signal and compare it to tests done in the laboratory.

The following hypotheses were made in the study.

1 At constant luminance the 12 inch signal would be rated always above the 8 inch signal at all apertures.

2 At constant intensity the 8 inch signal would be judged more detectable than the 12 inch signal at all apertures.

3 At constant voltage the 8 inch signal at bigger apertures would be judged more detectable than the 12 inch signal.

4 At closer distance the 12 inch signal would rated more detectable than the 8 inch signal.

METHOD

In this study 30 subjects were shown sets of two railroad-highway signals. They were shown one signal at constant luminance, constant voltage or constant intensity. They were asked to rate the detectability of the other signal for different apertures and at different distances.

Light Measurement

The researcher took measurements of the signals using a Spectra Brightness Spotmeter Photometer inside the laboratory. The signal luminance was measured and intensity was calculated. Black poster boards with 1 inch, 2 inch, 4 inch and 8 inch holes were used. The poster boards were circular with an outside diameter of 22 inches. The poster board was placed in front of each signal. The voltage of the signals were kept at 10 volts and luminances measured. Then the luminance of the signals was kept constant and the voltage reduced for different apertures. Then the intensity was kept constant and the voltage reduced for different apertures to get the desired luminance. Table 1 shows the measurements taken in the laboratory for the 8 inch signal.

TABLE 1

Photometric Measurements of 8inch Signal.

Condition	Aperture	Luminance	Voltage	Intensity
Const.volt	1"	154170	10v	78.11
Const.volt	2"	143892	10v	291.64
Const.volt	4"	44538	10v	361.08
Const.volt	8"	37686	10v	1222.12
Const.lum.	1"	29121	7.4v	14.75
Const.lum.	2"	29121	8.4v	59.02
Const.lum.	4"	29121	9.2v	236.09
Const.lum.	8"	29121	9.6v	944.37
Const.int.	1"	154170	10v	78.11
Const.int.	2"	38542.5	9.2v	78.11
Const.int.	4"	9635.63	8.6v	78.11
Const.int.	8"	2408.9	5.2v	78.11

The luminance measures were read from the photometer scale in footlamberts and converted to candelas/square meter. The voltage was kept constant at 10 volts. The intensities were calculated. The 12 inch diameter signal has a luminance of 29121 cd/sq.meter(8500 Ft-l). The voltage of the 8 inch signal was reduced to maintain this luminance and the voltage noted for different apertures. The intensity of the 1 inch aperture size at 10 volt was found to be 78.11 candelas. This was maintained constant and the voltage reduced to get the desired luminance for the other apertures.

These measurements were the used for showing the two signals to each subject at constant voltage, constant luminance, constant intensity in the field for different apertures.

Equipment

The signal equipment for this study was borrowed from Allard Inc, Ellsworth, Kansas who were involved in a project with the signals at Kansas State University. The 8 inch signal was made by Harmon Electronics Inc. It has a 10 volt 25 watt par 64 sealed beam lamp made by Westinghouse Electric Company. It has a "30-15" roundel(#7330-15) manufactured by General Signals Inc. The 12 inch signal was made by Safetran Signals Inc and has a plastic "deep" dish reflector. It uses a 10 volt 25 watt Westinghouse signal precision lamp. It has a"20-32" roundel (#7812-2032) manufactured by General Signals Inc.

The 8 inch signal lamp was a special order item. The lamp was a parabolic dish with a filament in front of the parabolic dish and a clear glass front that sealed the filament inside the dish. The roundel spread the light rays 15 degrees horizontally on either side of the center and 15 degrees downward.

The 12 inch signal had a clear CC6 incandescent lamp which was held in place by a light source holder. The parabolic "deep" dish was made of plastic. The roundel then spread the light 10 degrees horizontally on either side of the center and 32 degrees downward. Both roundels restricted the light from being directed vertically upward.

Subjects

Thirty subjects were chosen incidentally for the experiment. They were either faculty members or students of Kansas State University. Their ages ranged from 21 years to 54 years(Mean age=26 years). There were 25 males and five females in the study. All subjects were screened for color blindness using a Titmus Vision tester. Three subjects were found to be impaired in red-green color discrimination only. All other subjects passed the test. The test was a slide having digits in six colored circles and is a standard test for driver licensing. The experimentor contacted the subjects personally and requested their participation in the study. All subjects participated on a voluntary basis.

Experimental Setup

The 8 inch signal and 12 inch signal were mounted on two frames which were placed on top of a table. The center of the 8 inch signal was 44 inches(1.12m) from the ground and the center of the 12 signal was 42 inches(1.07m) from the ground. The signals were placed in front of Durland Hall facing east and were aimed towards the observer's position at 300 feet. Distances of 300 feet and 150 feet were marked off from the signal in its line of direction. A chair was placed at this distance facing the signal. Black poster boards with 1 inch, 2 inch, 4 inch and 8 inch holes were kept in front of the signals by using a "velcro" strip pasted on to the frame. Figure 9 shows the observer and the signals from a distance of 150 feet. Figure 10 shows the experimental setup from a distance of 10 feet from the

THIS BOOK CONTAINS SEVERAL DOCUMENTS THAT ARE OF POOR QUALITY DUE TO BEING A PHOTOCOPY OF A PHOTO.

THIS IS AS RECEIVED FROM CUSTOMER.

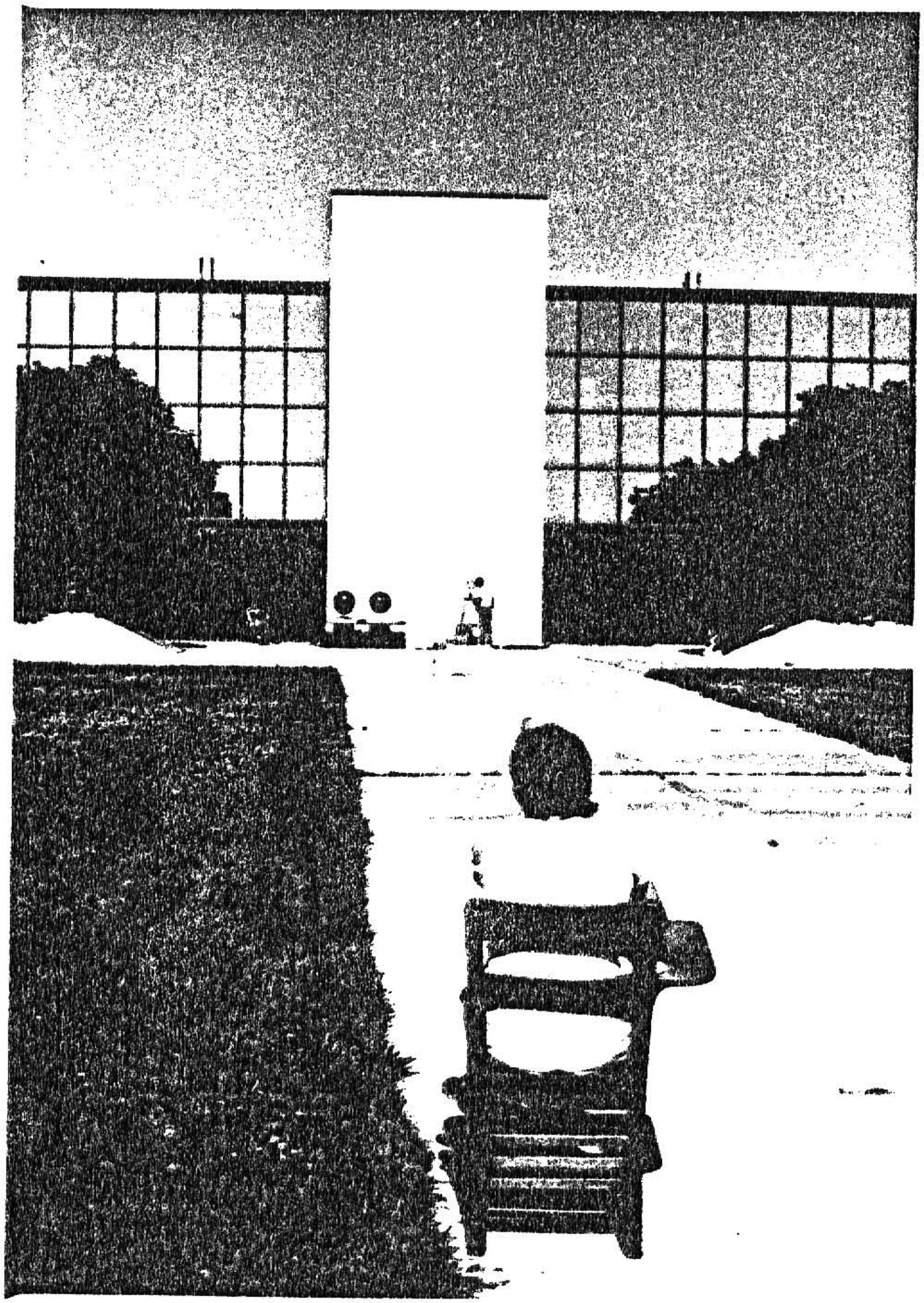

Figure 9. Experimental Setup with Observer from 150 Feet

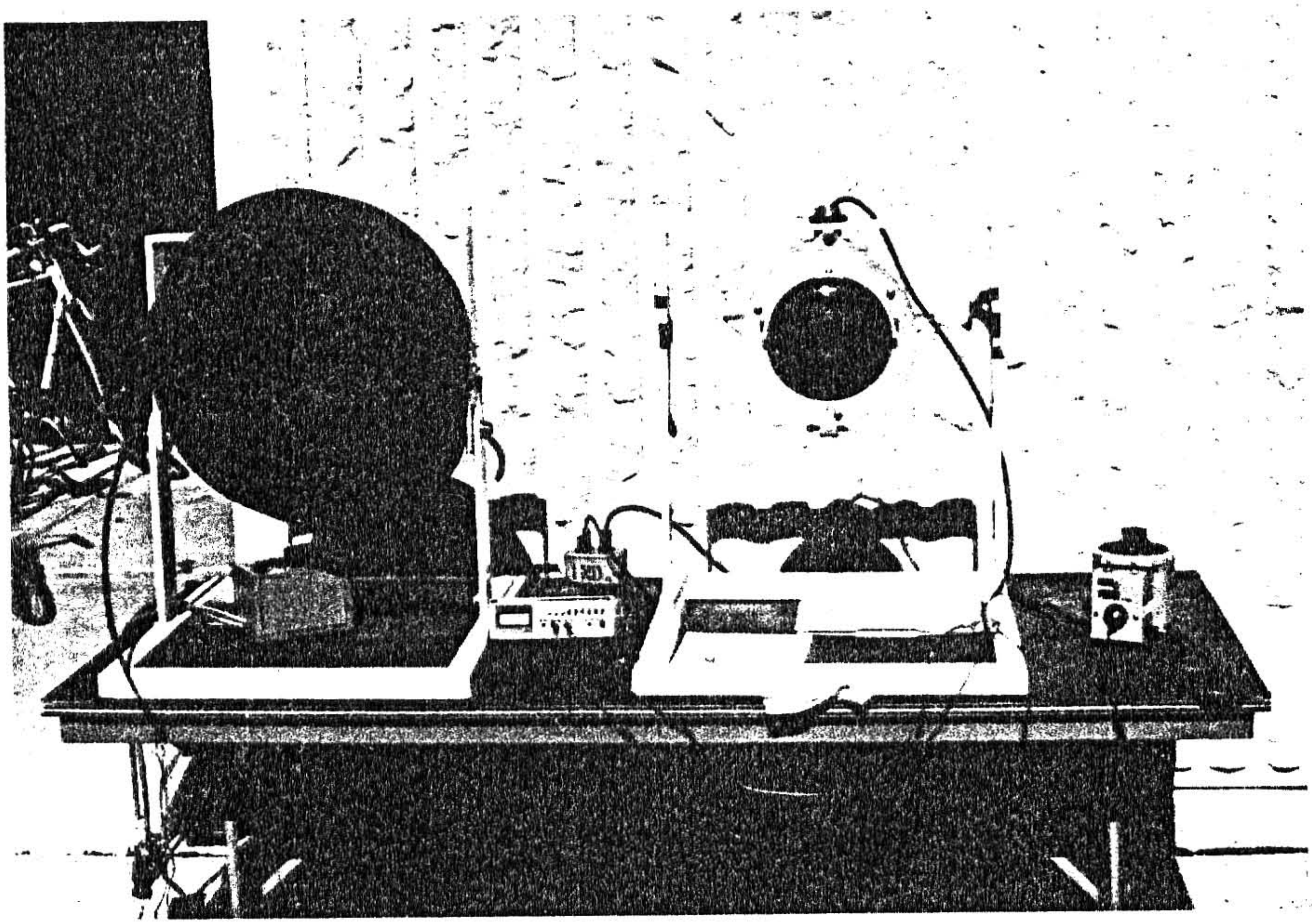

Figure 10. Experimental Setup at 10 Feet

signals. The signals were controlled by two auto stepdown transformers and the voltage was measured by a digital voltmeter. Table 2 shows the treatment combinations used in the experiment and the conditions, ie, voltage, luminance, intensity and aperture size for the signal.

Procedure

Upon arrival, each subject was greeted by the experimentor. The subject was then taken to the Illumination Laboratory where he or she was screened for color blindness. Then the subject was given the Instructions Form to read(Figure 11). After that the subject was cleared of any questions he or she had. Then the subject's signature was taken on an Informed Consent Form(Figure 12). The subject was then given two data forms on which to rate the signal(Figure 13).

The subject was then asked to take the seat at a distance randomly chosen (either at 300 feet or at 150 feet). The subject was then shown a "standard" 12 inch diameter signal kept at 10 volts. The 12 inch signal was always kept in its original size throughout the experiment. The subject was informed that the 12 inch signal had a rating of 10 on a scale of 1 to 20 in detectability. The subject was asked to rate the signal apertures of the 8 inch diameter signal. The subject then had to rate eight different signals of

TABLE 2

Treatment Combinations

Treatment	Aperture	Luminance	Voltage	Intensity
1	1"	154170	10v	78.11
2	2"	143892	10v	291.64
3	4"	44358	10v	361.08
4	8"	37686	10v	1222.12
5	1"	29121	7.4v	14.75
6	2"	29121	8.4v	59.02
7	4"	29121	9.2v	236.09
8	8"	29121	9.6v	944.37
9	1"	154170	10v	78.11
10	2"	38542.5	9.2v	78.11
11	4"	9635.63	8.6v	78.11
12	8"	2408.9	5.2v	78.11

Instructions And Informed Consent

You are about to participate in a study of apparent detectability in railroad-highway signals. You will be asked to sit in front of two signals at a distance. I will show you a standard signal and will give a rating on its detectability. You will then be shown 8 signals of different aperture. You are to rate the signals on a scale of 1 to 20 on their detectability based on the rating I gave for the signal. You are to base your rating on the standard and the question of how detectable is the signal. You will then be shown another standard and given a rating on its detectability. You will then rate 4 other signals on a scale of 1 to 20 on the basis of the standard and on how detectable they are. After you have done this you will move to another distance from the signal and go through the experiment again.

There will be no discomfort or risk involved in this study and the data collected by me will be kept confidential. You are free to stop your participation at any time. Naturally, I would prefer that you continue until the end so that I get all the data I need. If you have any doubts, feel free to ask questions at any time. Thank you for your cooperation.

Now, will you please sign the informed consent form.

Figure 11. Instructions Form

Informed Consent Statement

Having read the instructions, I hereby freely agree to be a subject in the research on apparent detectability of railroad-highway signals.

Signature	Age (years)	Sex (M/F)	Date

Figure 12. Informed Consent Form

DATA FORM

Subject No. ______________________ Date: ______________________

Distance: ______________________ Time: ______________________

Rating of Standard: ______________ Sky Condition: ______________

S. No.	Rating
1	
2	
3	
4	
5	
6	
7	
8	

Rating of Standard:

S. No.	Rating
1	
2	
3	
4	

Figure 13. Data Form

different aperture sizes with constant voltage or constant luminance shown randomly. Then the "standard" was set again for constant intensity by reducing the voltage on the 12 inch signal. The subject was then informed that this standard had a rating of 10 on a scale of 1 to 20 in detectability. The subject was asked to rate the next four randomly shown signals of apertures 1 inch, 2 inch, 4inch and 8inch. After the 12 ratings were taken the subject was asked to move to the other distance and to rate 12 more signals. The background luminance at a spot marked in between the signals was measured with a Spctra Brightness Spotmeter Photometer. Twenty five subjects were run during daytime and five subjects were run during twilight to night conditions.

RESULTS

The data obtained in this study were collected for each subject for different treatments and for different distances. The raw data for the 30 subjects are shown in Appendix 1.

The subjective ratings on the detectability of the signal were analyzed using the Statistical Analysis System. Table 3 shows this analysis. *Analysis on the interactions of* subjects on distance and the test of hypothesis using the subject distance interaction term as error term was done.

Analysis of variance on the mean ratings of each treatment is shown in Table 4.

Duncan's multiple range test was done on the treatment combinations, using the subjective rating of each subject as the dependent variable. This test was done without separating the conditions of constant voltage or constant luminance or constant intensity. Table 5 shows the results of this test.

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

TABLE 3

Analysis of Variance of Ratings

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: OBS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V
MODEL	81	20402.01250000	251.87669753	35.12	0.0001	0.816828	24.146
ERROR	638	4575.11944444	7.17103361		ROOT MSE		OBS MEA
CORRECTED TOTAL	719	24977.13194444			2.67787857		11.0902777

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUB	29	2037.59027778	9.80	0.0001
DIST	1	91.73472222	12.79	0.0004
SUB*DIST	29	323.39027778	1.56	0.0330
IPT	11	17903.88194444	226.97	0.0001
DIST*IPT	11	45.41527778	0.58	0.8500

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUB*DIST AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
DIST	1	91.73472222	8.23	0.0076

TABLE 4

Treatment Means

ANALYSIS OF VARIANCE PROCEDURE

MEANS

TRT	N	RAT
1	60	3.8333333
2	60	8.5166667
3	60	14.1333333
4	60	17.9166667
5	60	3.0833333
6	60	7.5166667
7	60	13.2333333
8	60	17.6833333
9	60	5.9000000
10	60	11.1666667
11	60	15.0000000
12	60	15.1000000

TABLE 5

Duncan's Multiple Range Test for Treatment Combination

Alpha=0.05, DF=70,MS Error=7.171

Means with same letter are not significantly different

Duncan Grouping	Mean	N	Treatment	Aperture	Condition
A	17.917	60	4	8"	constant voltage
A	17.683	60	8	8"	constant luminance
B	15.100	60	12	8"	constant intensity
B	15.000	60	11	4"	constant intensity
C B	14.133	60	3	4"	constant voltage
C	13.233	60	7	4"	constant luminance
D	11.167	60	10	2"	constant intensity
E	8.517	60	2	2"	constant voltage
F	7.517	60	6	2"	constant luminance
G	5.900	60	9	1"	constant intensity
H	3.833	60	1	1"	constant voltage
H	3.083	60	5	1"	constant luminance

Regression Analysis

A regression analysis was conducted on size versus rating for the three conditions separately. Tables 6, 7, and 8 show the regression for constant voltage, constant luminance and for constant intensity respectively. The subjective ratings were taken as the dependent variable and size of the signal was taken as the independent variable. There was no distinction made of the ratings at 300 feet and 150 feet and the observations were treated as ratings from only one distance. The dependent variable had 60 observations for each size of the signal. The independent variable, size, had four sizes of 1 inch, 2 inch, 4 inch and 8 inch diameter. A linear model was used to fit the regression model.

Table 6

Regression Analysis for Constant Voltage

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V
MODEL	3	7107.43333333	2369.14444444	253.63	0.0001	0.763261	27.329
ERROR	236	2204.50000000	9.34110169		ROOT MSE		RAT MEAN
CORRECTED TOTAL	239	9311.93333333			3.05632160		11.1833333

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
SIZE	3	7107.43333333	253.63	0.0001	3	7107.43333333	253.63	0.0001

TABLE 7

Regression Analysis for Constant Luminance

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V
MODEL	3	7389.81666667	2463.27222222	252.05	0.0001	0.762131	30.131
ERROR	236	2306.43333333	9.77302260		ROOT MSE		RAT MEAN
CORRECTED TOTAL	239	9696.25000000			3.12618339		10.3750000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
SIZE	3	7389.81666667	252.05	0.0001	3	7389.81666667	252.05	0.0001

TABLE 8

Regression Analysis for Constant Intensity

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V
MODEL	3	3181.74583333	1060.58194444	95.25	0.0001	0.547664	28.612
ERROR	236	2627.91666667	11.13524011		ROOT MSE		RAT MEA
CORRECTED TOTAL	239	5809.66250000			3.33695072		11.6625000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR >
SIZE	3	3181.74583333	95.25	0.0001	3	3181.74583333	95.25	0.000

DISCUSSION

As a result of the analysis of the data, an interesting factor that emerged was that there were no distance interaction effects. This means that the subjects were not affected by change in distance during the experiment in the way they rated the treatments, nor were the treatments affected by the change in distance.

Analysis of variance on the subject distance interaction and the distance treatment interaction did not yield any significance. This means that when subjects were constant and the distances were varied ,the change in distance did not significantly affect the ratings of the signal. Also when distance was kept constant and different subjects were tried ,the change in subjects did not significantly affect the the way they rated the treatments.

Similarly when treatments were shown at one distance, the way in which they were rated was not significantly different from the way the treatments were rated at the other distance.

Only the main effects namely subjects, treatments and distance influenced the variations. Of all the variations 87% were due to the treatments. Subjects contributed some variation but this was expected since each subject will respond in a different way and there are variations among subjects.

The test of hypothesis using the subject distance interaction as an error term, for testing whether distance had a significant effect on the ratings can be rejected since

$$Fc(1,29)=250.1 > F(1,29)=8.23$$

Hence the hypothesis that distance had any significant effect in the way the treatments were rated can be rejected.

Analysis of variance of the mean ratings of the treatments show that at constant voltage and at constant luminance the ratings were higher than at constant intensity. At constant intensity the 2 inch diameter signal was rated higher than the 12 inch signal which was given a rating of 10. Figures 14, 15 and 16 show plots of the signal size versus the mean ratings. It looks as if a second degree equation will fit the plots better. The linear model was satisfied adequately. It is found that on the average the 8 inch signal is rated highest and the 12 inch "standard" signal is found detectable equivalent to the 2 inch signal in all three conditions.

The Duncan's test for the ratings on the treatments yielded some surprising results. Treatments four and eight were found not to be different and were considered the same

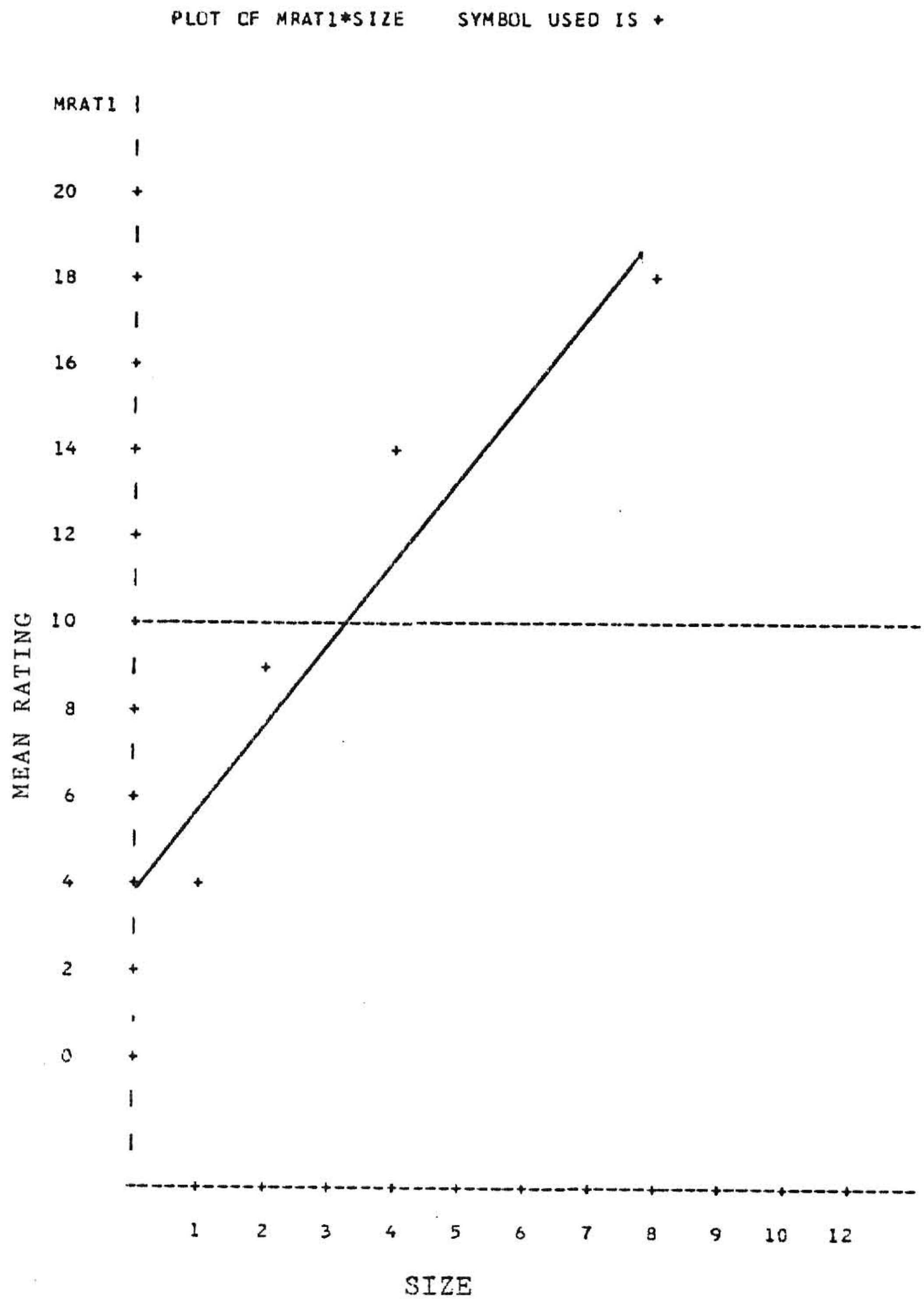

Figure 14. Plot of Mean Rating vs Size for Constant Voltage

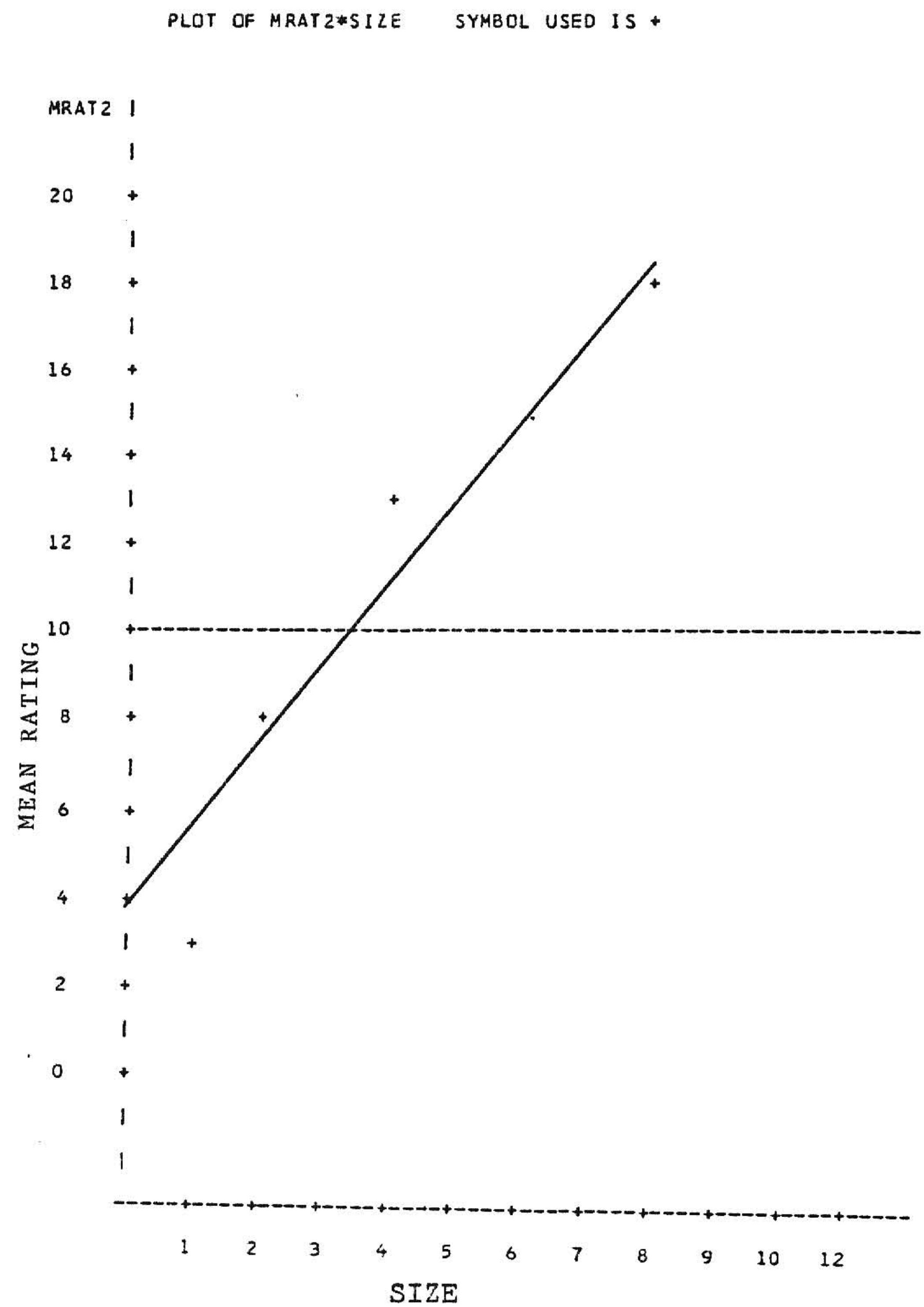

Figure 15. Plot of Mean Rating vs Size for Constant Luminance

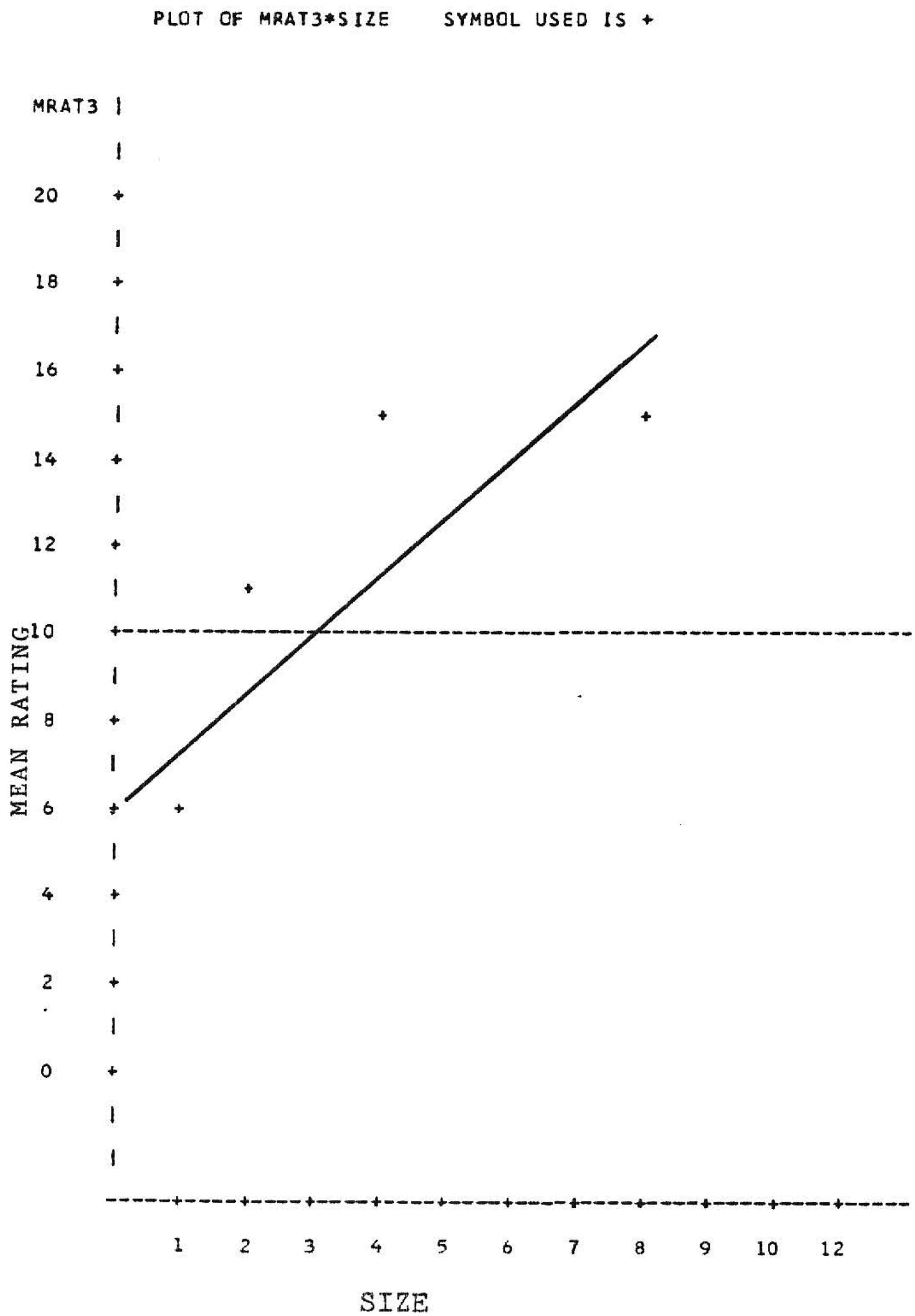

Figure 16. Plot of Mean Rating vs Size for Constant Intensity

even though treatment four is constant voltage condition and treatment eight, constant luminance. Treatments one and nine were identical but were showed under different conditions. Treatment one was found to be significantly different from treatment nine and it was found that treatment nine had a higher mean rating than treatment one.

From the results and the analysis it can be said that the subjects felt the 8 inch signal was the optimum size and that the 12 inch signal was not felt more detectable in any of the three conditions of constant voltage, constant luminance, constant intensity.

After analysing the data,analysis of variance and the Duncan means the hypotheses that at constant luminance and at closer distance the 12 inch signal will be found more detectable was rejected. The hypothesis that at constant intensity the 8 inch signal will be found more detectable was accepted.

Regression analysis on size of the signal versus the rating was done. The effect of distance was not taken into account and the ratings at different distances were taken as observations. The regression was done for the four aperture sizes of 1 inch, 2 inch, 4 inch and 8 inch diameter against the subjective ratings.

The ratings were separated for constant voltage, constant luminance and constant intensity. The model fitted was a simple linear one and it was found that the R-square value for constant voltage was 0.763, for constant luminance was 0.762 and for constant intensity was 0.547. In all the three conditions the model was found to be adequate. This can be explained that subjects rated higher for bigger aperture sizes of the signal. But what is striking to note is all these ratings were done using the 12 inch diameter signal as a standard and still 4 inch and 8 inch signals were rated higher. Figures 17, 18 and 19 show the plots of the observed rating values against size and predicted rating value against size for constant voltage, constant luminance and constant intensity.

After analysing the results we can say that size is not necessarily the criteria for humans to rate a signal more detectable. It was found that at constant intensity the 2 inch signal was rated higher than the 12 inch signal. It can be surmised from this that the intensity of the signal is the most important aspect of a signal for it to be considered detectable. It was found that subjects rate differently for the same sizes if the intensity is increased. So instead of just increasing the size of the signal from 8 inch to 12 inch diameter, it would be better to increase the intensity of the signal so that it is more detectable to humans.

Even at constant voltage and at constant luminance the 12 inch signal is not more detectable than a 8 inch or a 4 inch

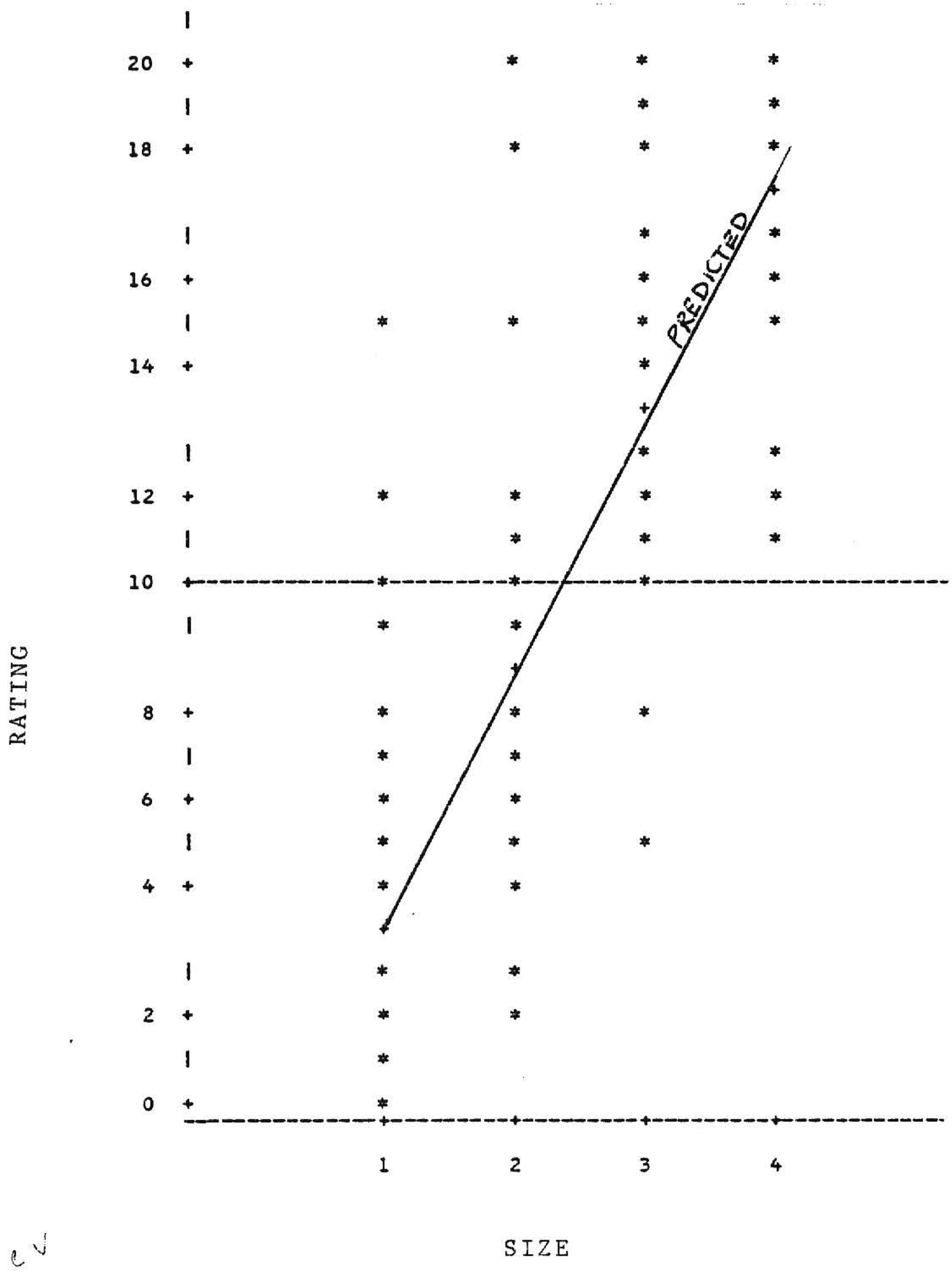

Figure 17. Plot of Observed Rating Values and Predicted Rating Values vs Size for Constant Voltage

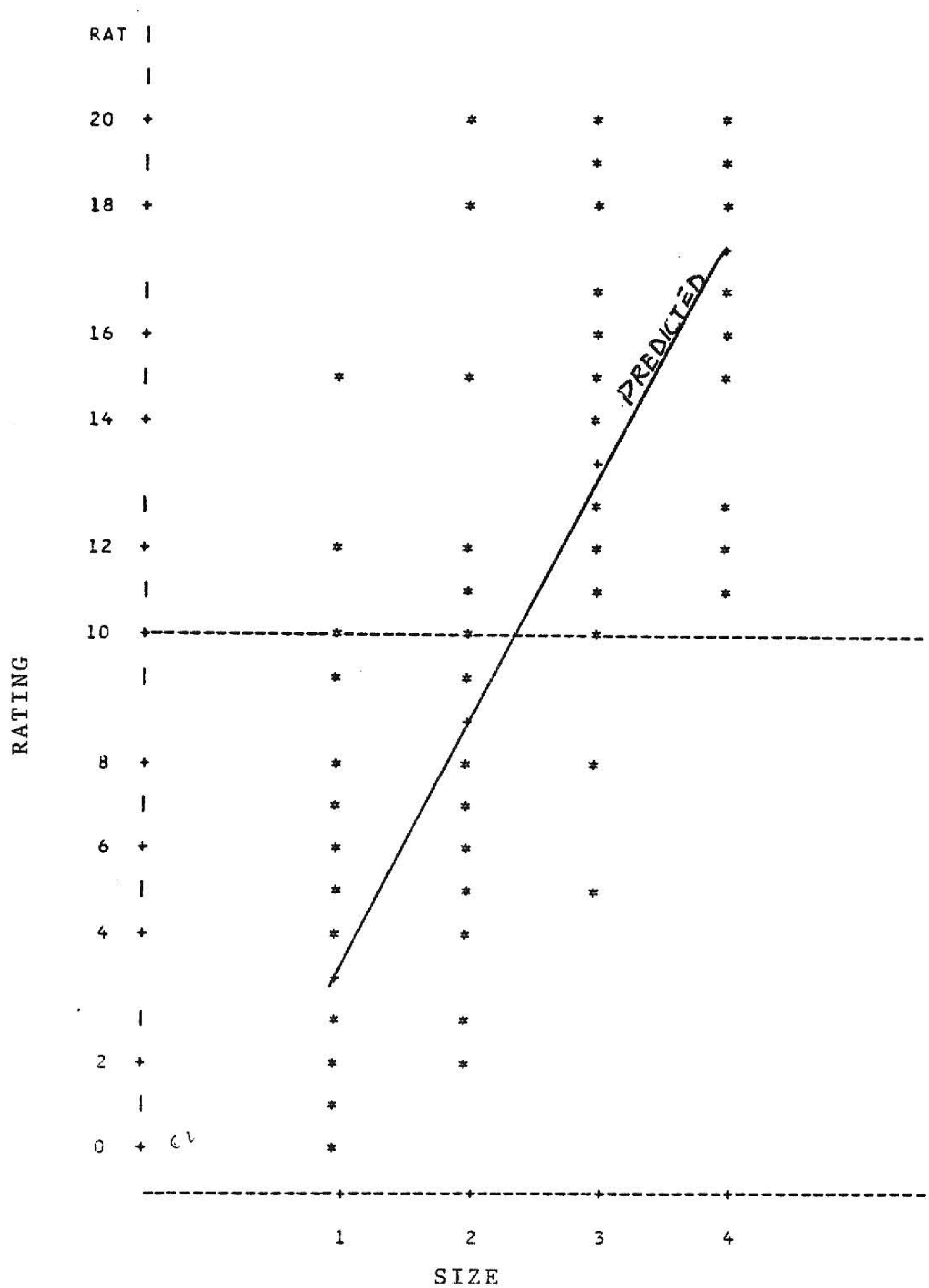

Figure 18. Plot of Observed Rating Values and Predicted Rating Values vs Size for Constant Luminance

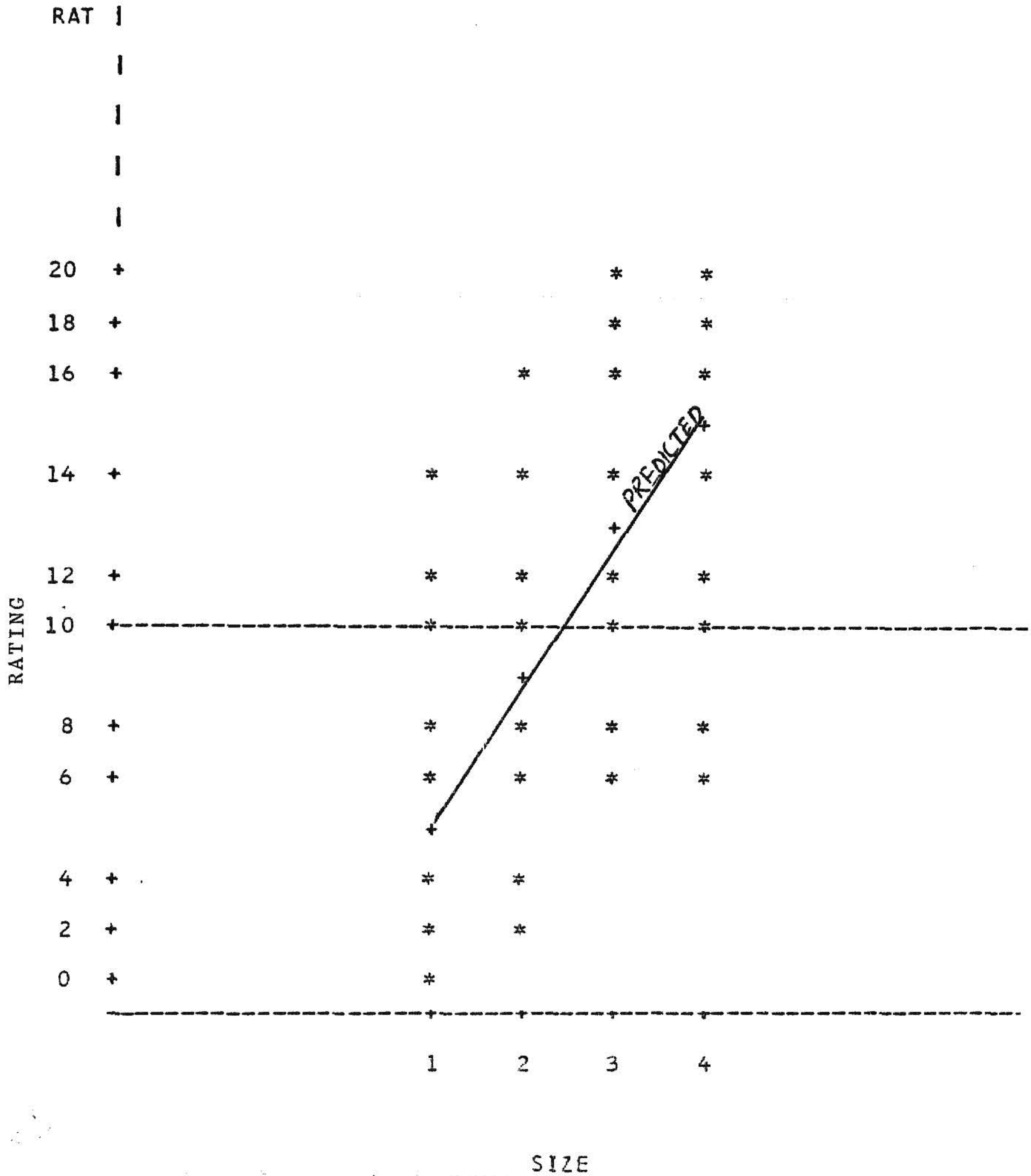

Figure 19. Plot of Observed Rating Values and Predicted Rating Values vs Size for Constant Intensity

sealed signal. The 8 inch signal used in this experiment used a sealed beam lamp and this may be a contributing factor for the higher ratings of the 8 inch signal.

CONCLUSIONS

1. There was clearly a size effect when the size of the signal was changed from 1inch aperture to 8 inch aperture. Judged detectability gets better when size is increased, however the 12 inch size is not any better than the 2 inch size.

2. Either there is an optimum size around 8 inch diameter or possibly the 8 inch signal hardware is superior in some unknown ways which resulted in this peculiarity in the subjective ratings.

This is despite the fact that the 12 inch hardware used is the best combination found in the pilot study.

3. Further research could test the possible hardware effect and should look at actual detectability in addition to judged detectability.

4. The evidence from this and previous study does not support changing 8 inch signal to 12 inch signals

In fact the forementioned further research might show that even more detectable signals might be designed to be less than 8 inches.

REFERENCES

Allard Inc.,Alternative ways to improve the visibilty of railroad-
highway crossing signals. Final Report for Federal Highway Administration, Washington, June 1983.

Brigano,M. and McCollough,H. The search for safety, commissioned by Union Switch and Signal Division. American Standard Inc, 1981, pp145-153.

Cole,B.L. and Brown,B. Optimum intensity of red road traffic signal lights for normal and protanopic observers. Journal of the Optical Society of America, 1966, 56(4), 516-522.

Cole,B.L. and Brown,B. Specification for road traffic signal light intensity. Human Factors, vol.10, No.3, 1968, pp 245-254.

Cunagin,W. and Abrahamson,T. Driver eye height: A field study ITE Journal, 1979, 34-36.

Dunlap,K. Color and form of traffic signals and sign in relation to Safety Proceedings of the 7th Annual Meeting, Highway Research Board, 1928, p.64.

Fisher,A.J and Cole,B.L. The photometric requirements of vehicular traffic signal lanterns Proceedings of the 7th Conference of the Australian Research Board, Adelaide, 1974.

Fisher,A.W. A history of flashing light crossing signals -

What they are and why. Railway Signaling and Communications, April, 1951, pp 240 -243.

Hall,M.C. and Greenbaum,L.J.Jr., Areas of vision and cockpit visibility Transactions of American Academy of Opthalmology and Otolarygnology, Volume LV, September-October, 1950, pp 74-88.

Hopkins,J.B. and White,E. Improvements of the effectiveness of motorist warnings at railroad-highway grade crossings, 1977

Hulscher,F.R. Practical implementation of performance for traffic light signals. Proceedings of the 7th Conference of the Australian Road Research Board, vol 7, part 5, New South Wales, 1974.

International Commission on Illumination., Light signals for road traffic control Publication No. 48, Paris France,1980.

King,G.F. The Visibility of circular traffic signal indicators, 60th Annual Meeting of the Transportation Research Board, 1975.

Mashour,M. Human Factors in Signalling Systems, ALMQVIST & WIKSELL International, Stockholm, Sweden, 1976.

Rudden,R.J. and Wasser,C.F. Motorists requirements for active grade crossing warning devices, Federal Highway Administration, Washington, 1977.

SAS user's Guide, SAS Institute, Cary, NC, 1982.

Appendix - I

Subjective Ratings

CBS	SUB	DIST	TRT	RAT
1	1	300	1	2
2	1	300	2	6
3	1	300	3	14
4	1	300	4	16
5	1	300	5	11
6	1	300	6	12
7	1	300	7	10
8	1	300	8	12
9	1	300	9	7
10	1	300	10	10
11	1	300	11	15
12	1	300	12	18
13	1	150	1	0
14	1	150	2	11
15	1	150	3	13
16	1	150	4	17
17	1	150	5	1
18	1	150	6	7
19	1	150	7	14
20	1	150	8	18
21	1	150	9	1
22	1	150	10	13
23	1	150	11	16
24	1	150	12	14
25	2	300	1	4
26	2	300	2	12
27	2	300	3	18
28	2	300	4	20

OBS	SUB	DIST	TRT	RAT
29	2	300	5	0
30	2	300	6	7
31	2	300	7	14
32	2	300	8	16
33	2	300	9	0
34	2	300	10	14
35	2	300	11	18
36	2	300	12	16
37	2	150	1	4
38	2	150	2	12
39	2	150	3	17
40	2	150	4	20
41	2	150	5	0
42	2	150	6	10
43	2	150	7	15
44	2	150	8	20
45	2	150	9	4
46	2	150	10	14
47	2	150	11	17
48	2	150	12	20
49	3	300	1	9
50	3	300	2	18
51	3	300	3	19
52	3	300	4	20
53	3	300	5	8
54	3	300	6	12
55	3	300	7	18
56	3	300	8	20

57	3	300	9	8
58	3	300	10	15
59	3	300	11	18
60	3	300	12	18
61	3	150	1	12
62	3	150	2	15
63	3	150	3	20
64	3	150	4	18
65	3	150	5	15
66	3	150	6	15
67	3	150	7	16
68	3	150	8	18
69	3	150	9	9
70	3	150	10	16
71	3	150	11	18
72	3	150	12	15
73	4	300	1	7
74	4	300	2	10
75	4	300	3	14
76	4	300	4	15
77	4	300	5	7
78	4	300	6	8
79	4	300	7	12
80	4	300	8	15
81	4	300	9	10
82	4	300	10	12
83	4	300	11	19
84	4	300	12	13
85	4	150	1	7

86	4	150	2	11
87	4	150	3	15
88	4	150	4	20
89	4	150	5	6
90	4	150	6	10
91	4	150	7	14
92	4	150	8	20
93	4	150	9	9
94	4	150	10	14
95	4	150	11	17
96	4	150	12	15
97	5	300	1	12
98	5	300	2	11
99	5	300	3	8
100	5	300	4	13
101	5	300	5	8
102	5	300	6	15
103	5	300	7	14
104	5	300	8	19
105	5	300	9	8
106	5	300	10	15
107	5	300	11	18
108	5	300	12	18
109	5	150	1	4
110	5	150	2	11
111	5	150	3	15
112	5	150	4	18

OBS	SUB	DIST	TRT	RAT
113	5	150	5	4
114	5	150	6	11
115	5	150	7	15
116	5	150	8	19
117	5	150	9	6
118	5	150	10	14
119	5	150	11	16
120	5	150	12	15
121	6	300	1	2
122	6	300	2	7
123	6	300	3	14
124	6	300	4	20
125	6	300	5	0
126	6	300	6	3
127	6	300	7	8
128	6	300	8	15
129	6	300	9	5
130	6	300	10	10
131	6	300	11	16
132	6	300	12	20
133	6	150	1	2
134	6	150	2	7
135	6	150	3	16
136	6	150	4	20
137	6	150	5	0
138	6	150	6	5
139	6	150	7	13
140	6	150	8	20

141	6	150	9	3
142	6	150	10	12
143	6	150	11	18
144	6	150	12	18
145	7	300	1	1
146	7	300	2	8
147	7	300	3	15
148	7	300	4	20
149	7	300	5	2
150	7	300	6	5
151	7	300	7	13
152	7	300	3	20
153	7	300	9	7
154	7	300	10	12
155	7	300	11	13
156	7	300	12	15
157	7	150	1	4
158	7	150	2	5
159	7	150	3	15
160	7	150	4	18
161	7	150	5	5
162	7	150	6	6
163	7	150	7	16
164	7	150	8	20
165	7	150	9	4
166	7	150	10	12
167	7	150	11	15
168	7	150	12	13

169	8	300	1	4
170	8	300	2	10
171	8	300	3	16
172	8	300	4	20
173	8	300	5	2
174	8	300	6	10
175	8	300	7	18
176	8	300	8	20
177	8	300	9	6
178	8	300	10	16
179	8	300	11	20
180	8	300	12	15
181	8	150	1	6
182	8	150	2	12
183	8	150	3	20
184	8	150	4	20
185	8	150	5	4
186	8	150	6	10
187	8	150	7	18
188	8	150	8	20
189	8	150	9	8
190	8	150	10	12
191	8	150	11	19
192	8	150	12	13
193	9	300	1	3
194	9	300	2	10
195	9	300	3	12
196	9	300	4	18
197	9	300	5	2
198	9	300	6	5

199	9	300	7	11
200	9	300	8	14
201	9	300	9	11
202	9	300	10	15
203	9	300	11	8
204	9	300	12	12
205	9	150	1	5
206	9	150	2	12
207	9	150	3	16
208	9	150	4	20
209	9	150	5	3
210	9	150	6	13
211	9	150	7	16
212	9	150	8	18
213	9	150	9	11
214	9	150	10	13
215	9	150	11	15
216	9	150	12	14
217	10	300	1	0
218	10	300	2	2
219	10	300	3	12
220	10	300	4	20
221	10	300	5	0
222	10	300	6	4
223	10	300	7	18
224	10	300	8	18
225	10	300	9	2

226	10	300	10	6
227	10	300	11	16
228	10	300	12	10
229	10	150	1	2
230	10	150	2	5
231	10	150	3	12
232	10	150	4	20
233	10	150	5	0
234	10	150	6	4
235	10	150	7	10
236	10	150	8	20
237	10	150	9	8
238	10	150	10	12
239	10	150	11	16
240	10	150	12	10
241	11	300	1	5
242	11	300	2	11
243	11	300	3	12
244	11	300	4	13
245	11	300	5	1
246	11	300	6	8
247	11	300	7	7
248	11	300	8	14
249	11	300	9	2
250	11	300	10	8
251	11	300	11	12
252	11	300	12	10
253	11	150	1	15

254	11	150	2	12
255	11	150	3	16
256	11	150	4	19
257	11	150	5	8
258	11	150	6	10
259	11	150	7	14
260	11	150	8	18
261	11	150	9	7
262	11	150	10	13
263	11	150	11	15
264	11	150	12	14
265	12	300	1	1
266	12	300	2	6
267	12	300	3	8
268	12	300	4	11
269	12	300	5	3
270	12	300	6	4
271	12	300	7	11
272	12	300	8	12
273	12	300	9	1
274	12	300	10	4
275	12	300	11	6
276	12	300	12	9
277	12	150	1	2
278	12	150	2	5
279	12	150	3	13

OBS	SUB	DIST	TRT	RAT
281	12	150	5	1
282	12	150	6	3
283	12	150	7	10
284	12	150	8	15
285	12	150	9	1
286	12	150	10	5
287	12	150	11	10
288	12	150	12	7
289	13	300	1	2
290	13	300	2	6
291	13	300	3	15
292	13	300	4	18
293	13	300	5	1
294	13	300	6	5
295	13	300	7	12
296	13	300	8	15
297	13	300	9	1
298	13	300	10	8
299	13	300	11	14
300	13	300	12	11
301	13	150	1	2
302	13	150	2	5
303	13	150	3	16
304	13	150	4	18
305	13	150	5	1
306	13	150	6	6

OBS	SUB	DIST	TRT	RAT
281	12	150	5	1
282	12	150	6	3
283	12	150	7	10
284	12	150	8	15
285	12	150	9	1
286	12	150	10	5
287	12	150	11	10
288	12	150	12	7
289	13	300	1	2
290	13	300	2	6
291	13	300	3	15
292	13	300	4	18
293	13	300	5	1
294	13	300	6	5
295	13	300	7	12
296	13	300	8	15
297	13	300	9	1
298	13	300	10	8
299	13	300	11	14
300	13	300	12	11
301	13	150	1	2
302	13	150	2	5
303	13	150	3	16
304	13	150	4	18
305	13	150	5	1
306	13	150	6	6

307	13	150	7	16
308	13	150	8	18
309	13	150	9	2
310	13	150	10	14
311	13	150	11	18
312	13	150	12	12
313	14	300	1	5
314	14	300	2	5
315	14	300	3	13
316	14	300	4	18
317	14	300	5	3
318	14	300	6	4
319	14	300	7	6
320	14	300	8	19
321	14	300	9	13
322	14	300	10	12
323	14	300	11	17
324	14	300	12	18
325	14	150	1	2
326	14	150	2	10
327	14	150	3	12
328	14	150	4	9
329	14	150	5	1
330	14	150	6	5
331	14	150	7	8
332	14	150	8	20
333	14	150	9	8
334	14	150	10	10
335	14	150	11	13

336	14	150	12	18

SAS

CBS	SUB	DIST	TRT	RAT
337	15	300	1	5
338	15	300	2	5
339	15	300	3	15
340	15	300	4	19
341	15	300	5	4
342	15	300	6	5
343	15	300	7	16
344	15	300	8	20
345	15	300	9	11
346	15	300	10	12
347	15	300	11	18
348	15	300	12	17
349	15	150	1	5
350	15	150	2	5
351	15	150	3	15
352	15	150	4	20
353	15	150	5	2
354	15	150	6	4
355	15	150	7	12
356	15	150	8	19
357	15	150	9	14
358	15	150	10	15
359	15	150	11	20

360	15	150	12	20
361	16	300	1	2
362	16	300	2	4
363	16	300	3	12
364	16	300	4	16
365	16	300	5	6
366	16	300	6	4
367	16	300	7	14
368	16	300	8	12
369	16	300	9	6
370	16	300	10	6
371	16	300	11	16
372	16	300	12	14
373	16	150	1	3
374	16	150	2	11
375	16	150	3	12
376	16	150	4	19
377	16	150	5	2
378	16	150	6	6
379	16	150	7	12
380	16	150	8	18
381	16	150	9	4
382	16	150	10	8
383	16	150	11	13
384	16	150	12	14
385	17	300	1	6
386	17	300	2	7
387	17	300	3	14
388	17	300	4	20

389	17	300	5	4
390	17	300	6	8
391	17	300	7	12
392	17	300	8	18

SAS

OBS	SUB	DIST	TRT	RAT
393	17	300	9	7
394	17	300	10	12
395	17	300	11	17
396	17	300	12	20
397	17	150	1	6
398	17	150	2	10
399	17	150	3	14
400	17	150	4	20
401	17	150	5	6
402	17	150	6	8
403	17	150	7	13
404	17	150	8	15
405	17	150	9	8
406	17	150	10	14
407	17	150	11	15
408	17	150	12	20
409	18	300	1	1
410	18	300	2	2
411	18	300	3	15
412	18	300	4	17

413	18	300	5	1
414	18	300	6	2
415	18	300	7	8
416	18	300	8	18
417	18	300	9	8
418	18	300	10	8
419	18	300	11	14
420	18	300	12	15
421	18	150	1	1
422	18	150	2	3
423	18	150	3	11
424	18	150	4	18
425	18	150	5	1
426	18	150	6	2
427	18	150	7	12
428	18	150	8	19
429	18	150	9	5
430	18	150	10	12
431	18	150	11	12
432	18	150	12	18
433	19	300	1	1
434	19	300	2	6
435	19	300	3	8
436	19	300	4	16
437	19	300	5	2
438	19	300	6	5
439	19	300	7	7
440	19	300	8	18
441	19	300	9	10

442	19	300	10	8
443	19	300	11	6
444	19	300	12	13
445	19	150	1	1
446	19	150	2	2
447	19	150	3	5
448	19	150	4	17

SAS

OBS	SUB	DIST	TRT	RAT
449	19	150	5	2
450	19	150	6	4
451	19	150	7	6
452	19	150	8	15
453	19	150	9	4
454	19	150	10	6
455	19	150	11	15
456	19	150	12	18
457	20	300	1	1
458	20	300	2	7
459	20	300	3	14
460	20	300	4	18
461	20	300	5	1
462	20	300	6	6
463	20	300	7	12
464	20	300	8	16
465	20	300	9	6

466	20	300	10	10
467	20	300	11	14
468	20	300	12	16
469	20	150	1	5
470	20	150	2	6
471	20	150	3	16
472	20	150	4	19
473	20	150	5	3
474	20	150	6	7
475	20	150	7	14
476	20	150	8	18
477	20	150	9	6
478	20	150	10	10
479	20	150	11	12
480	20	150	12	18
481	21	300	1	2
482	21	300	2	5
483	21	300	3	16
484	21	300	4	19
485	21	300	5	1
486	21	300	6	6
487	21	300	7	15
488	21	300	8	20
489	21	300	9	5
490	21	300	10	12
491	21	300	11	17
492	21	300	12	15
493	21	150	1	9
494	21	150	2	12

495	21	150	3	16
496	21	150	4	17
497	21	150	5	5
498	21	150	6	11
499	21	150	7	15
500	21	150	8	18
501	21	150	9	10
502	21	150	10	13
503	21	150	11	17
504	21	150	12	15

SAS

OBS	SUB	DIST	TRT	RAT
505	22	300	1	0
506	22	300	2	10
507	22	300	3	10
508	22	300	4	20
509	22	300	5	0
510	22	300	6	10
511	22	300	7	20
512	22	300	8	20
513	22	300	9	0
514	22	300	10	10
515	22	300	11	10
516	22	300	12	20
517	22	150	1	10
518	22	150	2	20

519	22	150	3	20
520	22	150	4	20
521	22	150	5	10
522	22	150	6	10
523	22	150	7	20
524	22	150	8	20
525	22	150	9	0
526	22	150	10	10
527	22	150	11	15
528	22	150	12	20
529	23	300	1	3
530	23	300	2	7
531	23	300	3	12
532	23	300	4	16
533	23	300	5	2
534	23	300	6	8
535	23	300	7	11
536	23	300	8	15
537	23	300	9	2
538	23	300	10	10
539	23	300	11	12
540	23	300	12	16
541	23	150	1	2
542	23	150	2	5
543	23	150	3	12
544	23	150	4	17
545	23	150	5	2
546	23	150	6	4
547	23	150	7	13

548	23	150	8	16
549	23	150	9	2
550	23	150	10	7
551	23	150	11	11
552	23	150	12	15
553	24	300	1	1
554	24	300	2	8
555	24	300	3	15
556	24	300	4	20
557	24	300	5	1
558	24	300	6	10
559	24	300	7	15
560	24	300	8	20

SAS

OBS	SUB	DIST	TRT	RAT
561	24	300	9	1
562	24	300	10	11
563	24	300	11	15
564	24	300	12	12
565	24	150	1	1
566	24	150	2	10
567	24	150	3	18
568	24	150	4	20
569	24	150	5	1
570	24	150	6	4
571	24	150	7	15

572	24	150	8	19
573	24	150	9	10
574	24	150	10	5
575	24	150	11	15
576	24	150	12	12
577	25	300	1	2
578	25	300	2	8
579	25	300	3	14
580	25	300	4	19
581	25	300	5	1
582	25	300	6	4
583	25	300	7	12
584	25	300	8	16
585	25	300	9	4
586	25	300	10	13
587	25	300	11	15
588	25	300	12	18
589	25	150	1	4
590	25	150	2	8
591	25	150	3	13
592	25	150	4	18
593	25	150	5	1
594	25	150	6	6
595	25	150	7	14
596	25	150	8	20
597	25	150	9	3
598	25	150	10	12
599	25	150	11	16
600	25	150	12	14

601	26	300	1	0
602	26	300	2	9
603	26	300	3	15
604	26	300	4	20
605	26	300	5	1
606	26	300	6	8
607	26	300	7	18
608	26	300	8	17
609	26	300	9	0
610	26	300	10	12
611	26	300	11	17
612	26	300	12	11
613	26	150	1	2
614	26	150	2	10
615	26	150	3	18
616	26	150	4	20

SAS

OBS	SUB	DIST	TRT	RAT
617	26	150	5	0
618	26	150	6	10
619	26	150	7	1
620	26	150	8	20
621	26	150	9	0
622	26	150	10	12
623	26	150	11	17
624	26	150	12	15

625	27	300	1	5
626	27	300	2	12
627	27	300	3	15
628	27	300	4	20
629	27	300	5	5
630	27	300	6	16
631	27	300	7	16
632	27	300	8	18
633	27	300	9	10
634	27	300	10	12
635	27	300	11	16
636	27	300	12	13
637	27	150	1	8
638	27	150	2	11
639	27	150	3	15
640	27	150	4	12
641	27	150	5	5
642	27	150	6	10
643	27	150	7	16
644	27	150	8	18
645	27	150	9	10
646	27	150	10	12
647	27	150	11	18
648	27	150	12	15
649	28	300	1	2
650	28	300	2	8
651	28	300	3	14
652	28	300	4	17
653	28	300	5	3

654	28	300	6	11
655	28	300	7	15
656	28	300	8	16
657	28	300	9	9
658	28	300	10	11
659	28	300	11	15
660	28	300	12	13
661	28	150	1	8
662	28	150	2	12
663	28	150	3	19
664	28	150	4	16
665	28	150	5	4
666	28	150	6	13
667	28	150	7	14
668	28	150	8	18
669	28	150	9	9
670	28	150	10	12
671	28	150	11	15
672	28	150	12	11

SAS

OBS	SUB	DIST	TRT	RAT
673	29	300	1	1
674	29	300	2	10
675	29	300	3	13
676	29	300	4	19
677	29	300	5	1

678	29	300	6	5
679	29	300	7	16
680	29	300	8	18
681	29	300	9	1
682	29	300	10	11
683	29	300	11	14
684	29	300	12	15
685	29	150	1	2
686	29	150	2	6
687	29	150	3	12
688	29	150	4	18
689	29	150	5	5
690	29	150	6	10
691	29	150	7	15
692	29	150	8	19
693	29	150	9	5
694	29	150	10	8
695	29	150	11	10
696	29	150	12	15
697	30	300	1	1
698	30	300	2	10
699	30	300	3	12
700	30	300	4	19
701	30	300	5	2
702	30	300	6	10
703	30	300	7	14
704	30	300	8	18
705	30	300	9	12
706	30	300	10	13

SAS

OBS	SUB	DIST	TRT	RAT
707	30	300	11	16
708	30	300	12	14
709	30	150	1	6
710	30	150	2	7
711	30	150	3	12
712	30	150	4	18
713	30	150	5	4
714	30	150	6	7
715	30	150	7	14
716	30	150	8	16
717	30	150	9	10
718	30	150	10	12
719	30	150	11	14
720	30	150	12	13

SIGNAL SIZE IN APPARENT DETECTABILITY OF RAILROAD-HIGHWAY CROSSING SIGNALS

by

PADMANABHAN RAMANKUTTY

B.E(Production),Government College of Technology,

Coimbatore, India. 1981

AN ABSTRACT OF A MASTER'S THESIS

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas.

1983

ABSTRACT

The main objective of this study was to find out subjective judgments of railroad-highway crossing signal sizes, in particular how subjects react to signal sizes at constant voltage, constant luminance and at constant intensity when asked subjectively to rate its detectability compared to a 12 inch signal.

Two sets of signals were mounted on frames kept on top of a table. One signal, the 12 inch diameter was kept as the standard. The other signal size was varied using black poster boards with holes of 1 inch, 2 inch, 4 inch and 8 inch punched in them. Each subject was asked to rate the four signal sizes for three conditions of constant voltage,constant luminance, constant intensity and at two distances of 300 feet and 150 feet from the signals.

The data was analysed and found that the treatments at constant voltage and constant luminance were rated higher than at constant intensity. In all the conditions it was found that the 2 inch signal size was rated equivalent to the standard. A regression analysis on the size versus rating yielded significant R-square values. But all these ratings were obtained by using the biggest size signal as the standard. Further research should be done to examine the possible hardware effect and should look at actual detectability in addition to judged detectability.