1263

REFLECTORIZED TRAFFIC REGULATOR VEST

MICHIGAN DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY DIVISION

TH7970.R4 S5 1985 c. 3
Reflectorized traffic
regulator vest

REFLECTORIZED TRAFFIC REGULATOR VEST

G. M. Smith

Research Laboratory Section
Materials and Technology Division

Research Project 77 G-229
Research Report R-1263

Lansing, August 1985

ACKNOWLEDGEMENT

We acknowledge and are grateful for assistance in conducting the field evaluations to the following persons: John Shaw, Vernerd Andrews, Vija Troms, Parker Fairey, Merle Tiedt, Marvin Scarlata, and John Truax.

The project was conducted under the general supervision of Marvin H. Janson.

Lawrence Holbrook conducted the statistical analysis.

EXECUTIVE SUMMARY

The Michigan Department of Transportation must do an increasing amount of nighttime maintenance and traffic control because of prohibitive daytime traffic volumes. The nighttime fatality-injury rate of pedestrians is several times the daytime rate, carrying the implication that a traffic regulator working at night is also in much greater jeopardy than during the day. This study was undertaken to find out which design of reflectorized vests would provide maximum protection for traffic regulators (flaggers) working at night or under heavy overcast or stormy conditions, where motorists would use headlights.

The current "Federal Manual on Uniform Traffic Control Devices" mandates a reflectorized traffic regulator vest for nighttime work, without requiring any particular color, size, or shape of the reflectorization. The Federally required daytime color is orange. Many states, including Michigan, presently require a fluorescent orange vest.

The STOP sign normally held by a traffic regulator was investigated for brightness adequacy, because STOP sign visibility was considered to be an integral part of traffic regulator attention value and recognizability, in addition to the expected STOP sign function of transmitting a message to drivers.

The results of this study are expected to be transmitted to the subcommittee on Construction and Maintenance of the National Advisory Committee of the "Manual on Uniform Traffic Control Devices." The Manual is used as a standard by states, counties, and cities that employ traffic regulators at night on maintenance work.

<u>Initial Study</u> - An initial observer field study of 11 reflectorized patterns of a variety of shapes was followed by a second series of definitive field studies. The initial study indicated the need for:

1) A pattern with four or five arms radiating from the center. In general, round or striped patterns were inferior.

2) A reflectorized pattern which is also fluorescent. The preferred patterns obscured so much of the area of the fluorescent vest that there was a prohibitive loss of <u>daytime</u> visibility of the vest.

3) Adequate brightness of the STOP sign held by a traffic regulator for maximum conveyance to an approaching motorist of the purpose for the traffic regulator, and for optimum recognition of the flagger.

<u>Final Study Series</u> - The final series of studies of reflectorized traffic regulator vests employed observers travelling in vehicles at the maximum 45 mph speed through a simulated maintenance zone, viewing two vests at a time. The observers based their choices of the better reflectorized

pattern of the pair on two main criteria, 1) visibility, conspicuity, or attention value, and 2) recognizability of pattern.

Observers chosen at random viewed differently shaped reflectorized patterns on vests, under two lighting environments at night: 1) rural with no extraneous glare sources, and 2) with two sets of upper-beam headlamps very near the vests and aimed at the observers. The upper-beam headlamps simulated either a severe oncoming headlight condition on a rural roadway or the glare levels found in many urban lighting environments. The rural lighting environment test was repeated on a night with very dense fog.

Because an informal field survey found that most traffic regulators stand with the sides of their bodies facing traffic or partially facing traffic, a study was conducted using vests with and without reflective side patterns of various shapes. Observers also evaluated the impact of a flagger wearing reflectorized gauntlets, leglets, and safety helmet.

Three levels of STOP sign brightness were investigated using three different reflectorized materials affixed to STOP sign faces:

1) Low - enclosed bead ('engineering grade') reflective sheeting.

2) Medium - encapsulated bead ('high intensity') reflective sheeting at approximately three times the brightness of enclosed bead sheeting.

3) High - encapsulated prism ('cube-corner') reflective sheeting at approximately 10 times the brightness of enclosed bead sheeting at normal viewing angles.

Results of Final Studies

Shape, Size - The shape and size of the reflectorized vest pattern should be a chevron over an inverted chevron as illustrated in Figure 4 in the report. The stripes of reflectorized material which make up the chevron pattern need to be no wider than 2 in.

Observers preferred vests with reflective side patterns, and picked 4 in. by 4-in. wide horizontal stripes as superior to 4 in. by 2-in. wide horizontal stripes as side patterns. A minimum of two such 4 by 4-in. blocks should be used as reflectorized side patterns.

For very dense foggy conditions a fully reflectorized vest is superior because drivers may not perceive any shape and require sheer size and brightness for detection of the vest.

Color - For nighttime and dusk, the reflectorized pattern should be yellow for greatest conspicuity and recognizability. Observers considered the Federal Highway Administration (FHWA) Transportation Orange color greatly inferior to the other four colors evaluated (yellow, red, white, and green). The color yellow would appear as the brightest (along with white) of those evaluated to drivers with color-deficient vision.

The daytime color of the reflectorized vest pattern affixed to the fluorescent yellow-orange base vest material should be fluorescent yellow. A basic fluorescent yellow-orange vest is not bright enough even on a cloudless day to be easily visible if the traffic regulator is standing in front of a vehicle painted Transportation Orange (FHWA). The addition of a fluorescent yellow pattern greatly enhances the conspicuity of the vest against such an orange background.

Brightness - The nighttime brightness should be a minimum of approximately 15 foot-Lamberts (51.4 candelas/sq m) when illuminated by automotive lower-beam headlamps at 400 ft. This level of brightness approximates that of 'high intensity' (encapsulated bead) reflective sheeting used on roadway signs.

STOP Sign - Many observers failed to notice the low-level brightness enclosed bead STOP sign next to the brightest reflectorized vests but no observers failed to notice the high level brightness STOP sign (encapsulated prism reflective sheeting). Moreover, a high level brightness of STOP sign was found to assist in detection of a traffic regulator standing sideways to traffic.

Therefore, the brightness of the STOP sign should be on a par with, or preferably exceed, the brightness of the flagger vest, as does the brightness of the encapsulated prism coated STOP sign. Should problems with procurement or application of encapsulated prism material arise, encapsulated bead ('high intensity') will yield a STOP sign brightness similar to the recommended vest brightness.

Additional Reflectorization - Almost all observers felt that reflectorized gauntlets, anklets, and safety helmet contributed significantly to conspicuity of the flagger especially when arms, feet or head were moved. Reflectorized stripes or piping on clothing or extremities would accomplish a similar end. A drawback to reflectorization of clothing other than vests is the greater inventory and cost involved.

Ventilation - Most people wearing experimental vests experienced excessive warmth during summertime evaluations. Therefore, it is recommended that vest ventilation be provided by means of perforations in the non-reflective portions of the vest or by the use of mesh or screen fabric as the base vest material to which the reflective material is fastened.

Summary of Recommendations

Shape - Front and back panels of vest: Chevron over inverted chevron, 2-in. stroke width.
Side: Two 4 by 4-in. squares spaced vertically. See Figure 4 for detailed dimensions.

Color - Night: Reflectorized yellow.
Day: Fluorescent yellow.

Brightness - A material that will yield a minimum of 15 ft-L when illuminated by automotive low-beam headlamps at 400 ft. Reflectorized pattern on vest should approximate brightness of 'high intensity' encapsulated bead reflective sheeting.

Note: Ventilation for wearer comfort is recommended by means of perforating non-reflective portions of the vest, or using mesh or screen fabric for the base vest material.

INTRODUCTION

Purpose

The purpose of this report is to provide a means for improving the safety of personnel working as traffic regulators (flaggers) during hours of dusk and darkness, primarily by upgrading the nighttime visibility, conspicuity, and recognizability of the safety vest worn by the traffic regulator.

Goals and Objectives

The ultimate goal of this report is a set of recommendations for designing a reflectorized pattern for a traffic regulator vest which will provide adequate conspicuity and recognizability of the traffic regulator to the motorist at night.

Objectives to be realized in attaining this goal are:

1) To summarize and integrate pertinent findings of previously reported Michigan Department of Transportation studies of reflectorized traffic regulator vests (1, 2, 3) with a more detailed discourse on a final more definitive series of studies of reflectorized vests.

2) To recommend improvements in the visibility of the STOP sign normally held by the traffic regulator because STOP sign visibility is important to traffic regulator conspicuity and recognizability.

3) To employ observers in determining the important design parameters of a reflectorized traffic regulator vest; to confirm results of previous studies where the observers were stationary with a final series of studies with observers travelling in a vehicle.

4) To determine the relative merits of pattern reflectorized vests as compared with a fully reflectorized vest in which the whole trunk of the flagger is reflectorized.

Background

Nighttime Departmental use of vests was determined to be on the order of 5 percent of the total maintenance hours. However, the Department normally furnishes the vest design to counties and contractors who may, and often do, work on 24-hour per day projects. Furthermore, in very overcast daytime conditions, the reflectorized feature becomes a necessary adjunct to the fluorescent vest when motorists are using their vehicle headlamps.

Detection of the flagger vest alone is not considered an adequate criterion for effectiveness of a flagger vest. Recognition is also necessary for the driver to make a decision.

A driver may cover as much as 25 ft before the driver's eyes are fixated on an object in the roadway. Generally, it takes approximately one-quarter second for the eyes to move and converge on an object such that the objective falls in the foveal region of the retina where the highest visual acuity is attained.

Recognition of the object occurs next in the chain of events. Any reflectorization of a flagger vest should be such as to permit recognition of the traffic regulator by the driver, or at least recognition of the reflectorized pattern shape as that worn by a traffic regulator. Therefore, the reflectorized pattern shape should be not only recognizable but standardized as well so that drivers might become accustomed to a certain shape.

Results of two previous studies in 1973 (1) and 1976 (2) of reflectorized traffic regulator vests were submitted January 25, 1977, to the Subcommittee on Construction and Maintenance of the National Advisory Committee of the "Manual on Uniform Traffic Control Devices" along with a request for guidance for further research on color and shape of the reflectorized pattern.

In response to the Department's recommendations concerning the pattern shape and reflectorized color for traffic regulator apparel, the Subcommittee on Construction and Maintenance recommended additional experimentation. The 1976 Department report (2) had recommended a yellow 'stick man' reflectorized pattern.*

In November 1977, R. E. Conner of the Office of Traffic Operations, FHWA, transmitted an Official Ruling Cn-35 recommending that a proposal for further research be submitted with the considerations that:

"1. Your previous research has been static testing only.

2. The introduction of yellow into the construction zone would be a significant departure from the currently recognized color code.

3. Your 'stick man' figure was never night tested against a fully reflectorized vest. This should be a major focus of further research, regardless of the fact that the fully reflectorized vest may have less daytime visibility."

Because the "currently recognized color code" (2 above) as mandated by the Federal "Manual on Uniform Traffic Control Devices" (MUTCD) is orange for daytime, and should be reflectorized for nighttime use, and because the traffic regulator vest in use in Michigan and in many other states is a fluorescent yellow-orange or 'blaze orange,' a search for an available orange fluorescent reflectorized material was conducted.

*Refer also to Michigan Departmental Research Report No. R-873 (1) which recommended a dual purpose fluorescent and reflectorized vest.

The Reflexite Corp. had developed a fluorescent and reflectorized material which was fluorescent yellow-orange under daylight illumination and showed an acceptable reflected yellow-orange color under headlight illumination. Sufficient material was obtained to fabricate two vests.

In an initial test it was decided to use the fluorescent yellow-orange basic vest color, and a non-fluorescent orange vest was included to obtain a difference at dusk. The tests were conducted at night and at dusk with an additional test at night during an extremely heavy fog. Patterns on the vests were varied and brightness was varied by controlling exposed areas.

Observers in moving vehicles recorded their preferences from paired comparisons of six orange vests. The observers were asked to compare one vest with another on the basis of: 1) visibility, conspicuity, or attention value; and, 2) recognizability.

A STOP sign was positioned midway between each vest pair presentation. After the presentations, the observers were asked whether they had noticed or had been able to read the STOP sign.

Results as reported in a Progress Report (3) indicated:

1) The brighter the vest the better, and that a distinctive pattern was preferred.

2) Most observers had not noticed the STOP sign or had not been able to read the word 'stop,' evidently because of its low brightness. The STOP sign was coated with enclosed bead ('engineering grade') reflective sheeting.

3) A reflectorized pattern consisting of a chevron over an inverted chevron (Fig. 1B) was preferred by a large margin to an orange reflectorized pattern with humanoid ('stick man') pattern (Fig. 1A).

4) The chevron over inverted chevron shape was preferred by an even larger margin to a fully reflectorized vest with a rectangular (long axis vertical) pattern, and very strongly preferred to a pattern with horizontal stripes (Fig. 2).

The results of the two previous MDOT studies with stationary observers were confirmed.

The recommendations for further research from the Progress Report on the above study (3) were:

1) Other (vest) factors that should be investigated are:

a) vest color - orange, white, yellow, and red,
b) observers viewing vests against on-coming headlights,
c) vests turned through various angles, and
d) urban (lighting environment) situation.

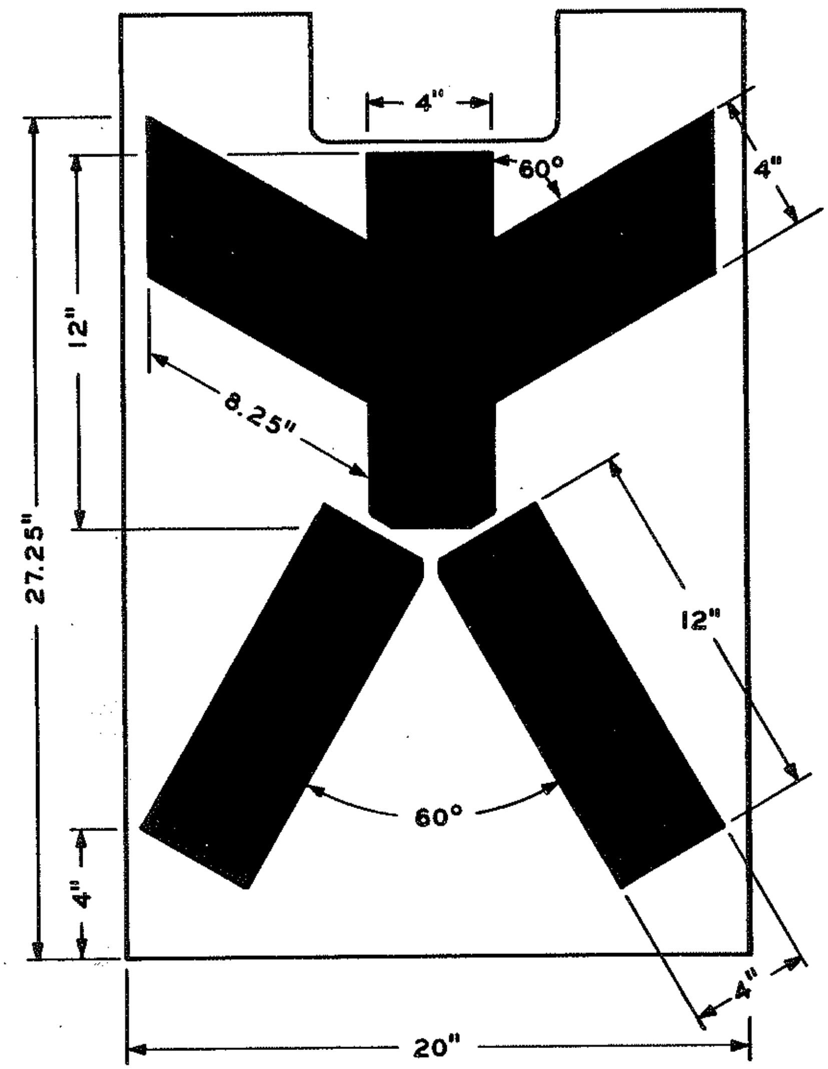

Figure 1A. 210 sq in. reflectorized material.

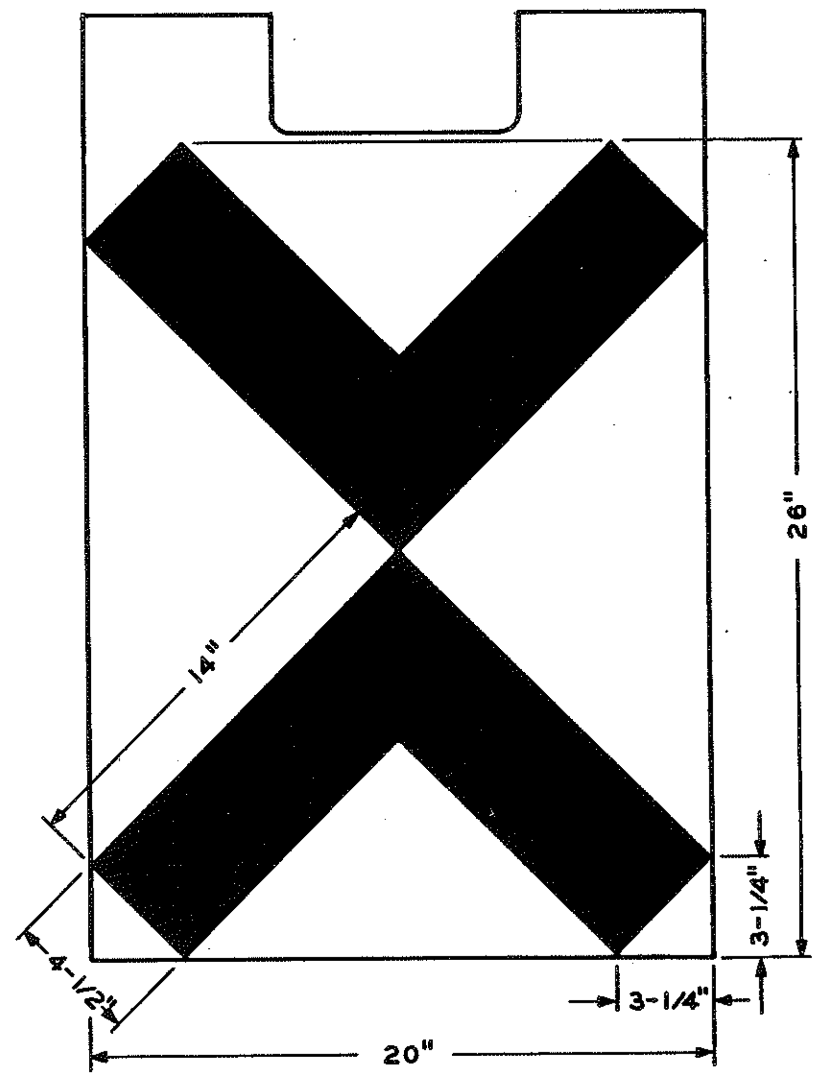

Figure 1B. 252 sq in. reflectorized material.

■ fluorescent and reflectorized

□ fluorescent but not reflectorized

Figure 1. Humanoid ('stickman') and double chevron vest patterns.

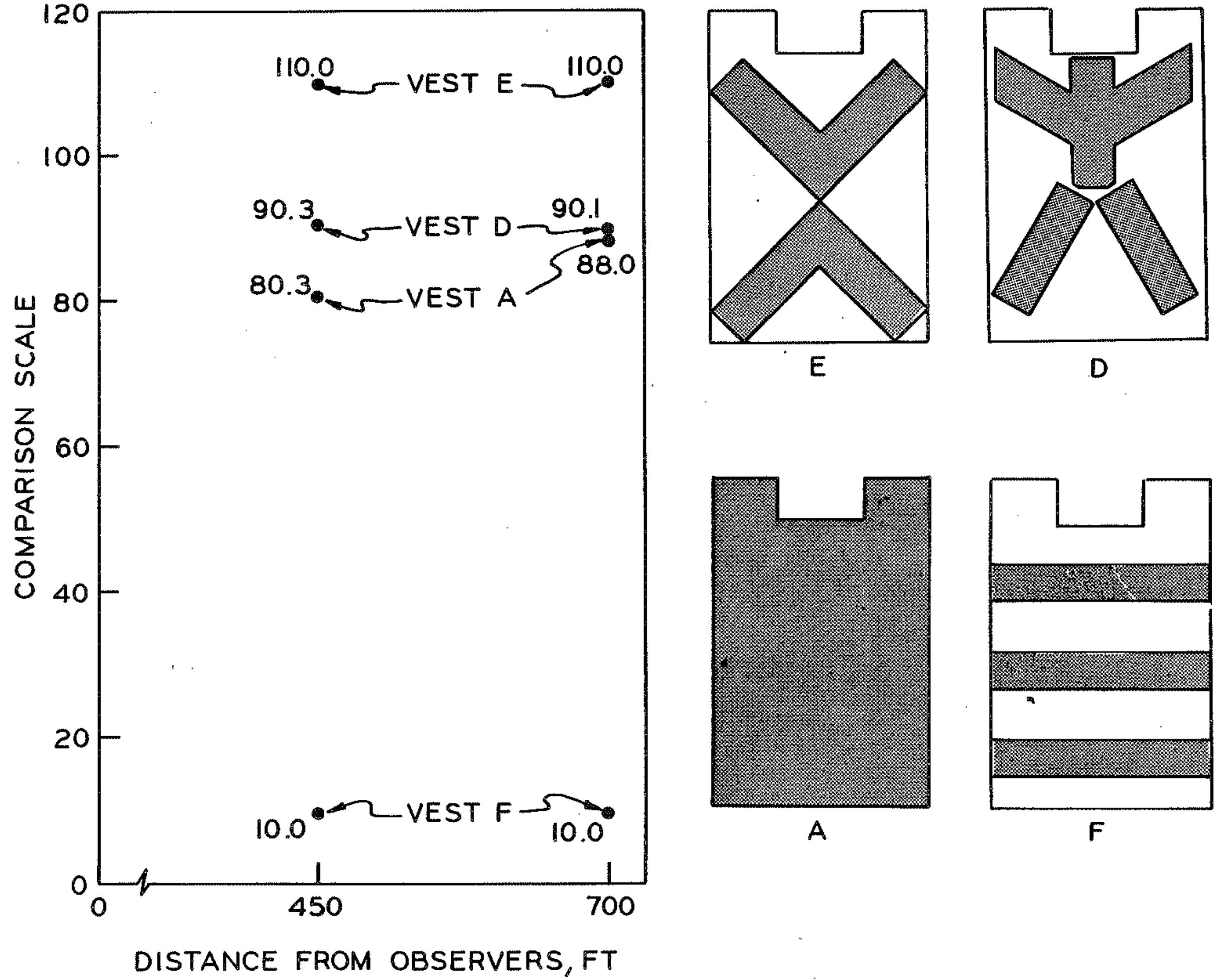

Figure 2. Relative observer responses at night to vests A, D, E, and F in pair comparison tests.

2) The Reflexite material should undergo field trials of up to one year on construction projects to determine feasibility and durability.

3) The effect of reflectorized gauntlets, leglets, and hats in addition to reflectorized vest should be investigated.

4) Increased STOP sign luminance should be investigated.

In the final series of studies reported later, the testing procedure was structured to respond to the recommendations expressed at the conclusion of the Progress Report as follows:

1) Vest Factors - Reflectorized and fluorescent vest materials of the following colors were obtained from the Reflexite Corp.: red, orange (similar to highway construction orange), yellow, green, and white. Their daytime equivalents in fluorescent colors were, respectively, (Dayglo Corp. fluorescent pigment names): 'Rocket Red,' 'Blaze Orange,' 'Saturn Yellow,' and 'Signal Green.' Current Michigan DOT specifications (6.31.02e, 1984) require the daytime color of the traffic regulator vest (as well as traffic cones and flags) to be Switzer Bros. Day-Glo, Blaze, or Fire Orange, or the Minnesota Mining and Manufacturing Company No. 3483 fluorescent yellow-orange, or No. 3484 fluorescent red-orange. The pattern shapes used were as illustrated in Figure 1A and 1B.

2) Lighting Environment - Observers viewed pairs of vests against two sets of vehicle upper-beam headlamps facing them.

A typical urban lighting environment was noted from previous measurements as producing disability glare at the drivers' eyes approximately equivalent to two sets of upper-beam headlamps. Therefore, the results of the on-coming headlights test were judged to be similar to those which could be obtained in an urban lighting environment.

3) Orientation of Vests - Observers approached vests from frontal, three-quarter, and side directions.

4) Auxiliary Reflectorization - Observers viewed flaggers wearing reflectorized helmets, gauntlets, and leglets.

5) STOP Sign - A high level brightness encapsulated prism reflectorized material (Reflexite Corp.), that increased the luminance of the standard STOP sign in excess of 1,000 percent, in addition to a medium level brightness encapsulated bead ('high intensity') reflective sheeting material, were used on the STOP signs. The reflective sheeting affixed to the standard STOP sign employed in previous studies was a relatively low level brightness 'engineering grade' enclosed glass bead reflective sheeting. This type of reflective sheeting was not included in the final series of studies because of its low conspicuity and visibility.

PREVIOUS RESEARCH

Austin, et al (4) calculated that nighttime pedestrian fatalities were approximately 18 times higher than expected, based on daytime fatality rates and nighttime traffic and pedestrian volumes. It follows that a traffic regulator, as well as a pedestrian, would also have a much higher nighttime risk than a daylight hours risk of being struck by a vehicle. Although nighttime use of vests is proportionately much less than their daytime use (perhaps less than one-tenth) the nighttime use is much more important in terms of safety than the daytime use in view of the approximately 18 times greater chance of a flagger being fatally injured at night. The foregoing presumes, of course, that without extra protection a flagger's chances of being struck by a vehicle are similar to those of a pedestrian. Lower average vehicle speed and driver caution in maintenance or construction zones may be a factor in altering such comparisons.

Blomberg (5) in a U. S. Department of Transportation report of a mail survey of the public and appropriate officials (police, judges, traffic engineers, AAA, etc.) found heavy support for mandatory use of a retroreflective material by roadway workers at night. The respondents also felt that the color and reflectivity of the reflectorized material should be standardized and be provided by employers.

Based on previous studies by this Department (1, 2, 3) we considered the following characteristics to be the important visual attributes of a reflectorized vest pattern: shape, color, brightness, and size. The status of known research of these four factors is as follows:

Shape

Harkness (6) studied the human response in a highway simulator to a variety of shapes (circle, rectangle, square, diamond, octagon, inverted triangle) adopted as sign shapes by the National Joint Committee on Uniform Traffic Control Devices, as well as driver reaction to the ellipse, semi-circle, pentagon, base-down triangle, and others. The base-down triangle ranked highest of both groups of symbols in recognizability, thus indicating that a basic triangular shape should be included in our study.

In a 1973 Michigan Department of Transportation study reflectorized vest patterns were evaluated at night with observers choosing the better pattern in a two-at-a-time comparison of seven patterns (1). The seven pattern designs had evolved out of a preliminary investigation of 11 different patterns. In general, round or striped patterns were inferior. Figure 3 shows, by means of pair comparison scaling (see Appendix) that patterns E, C, and D were very close in observer preference.

Color

Fluorescent yellow-orange has the greatest visibility distance of any color during the daytime. Fluorescent yellow-orange combined with

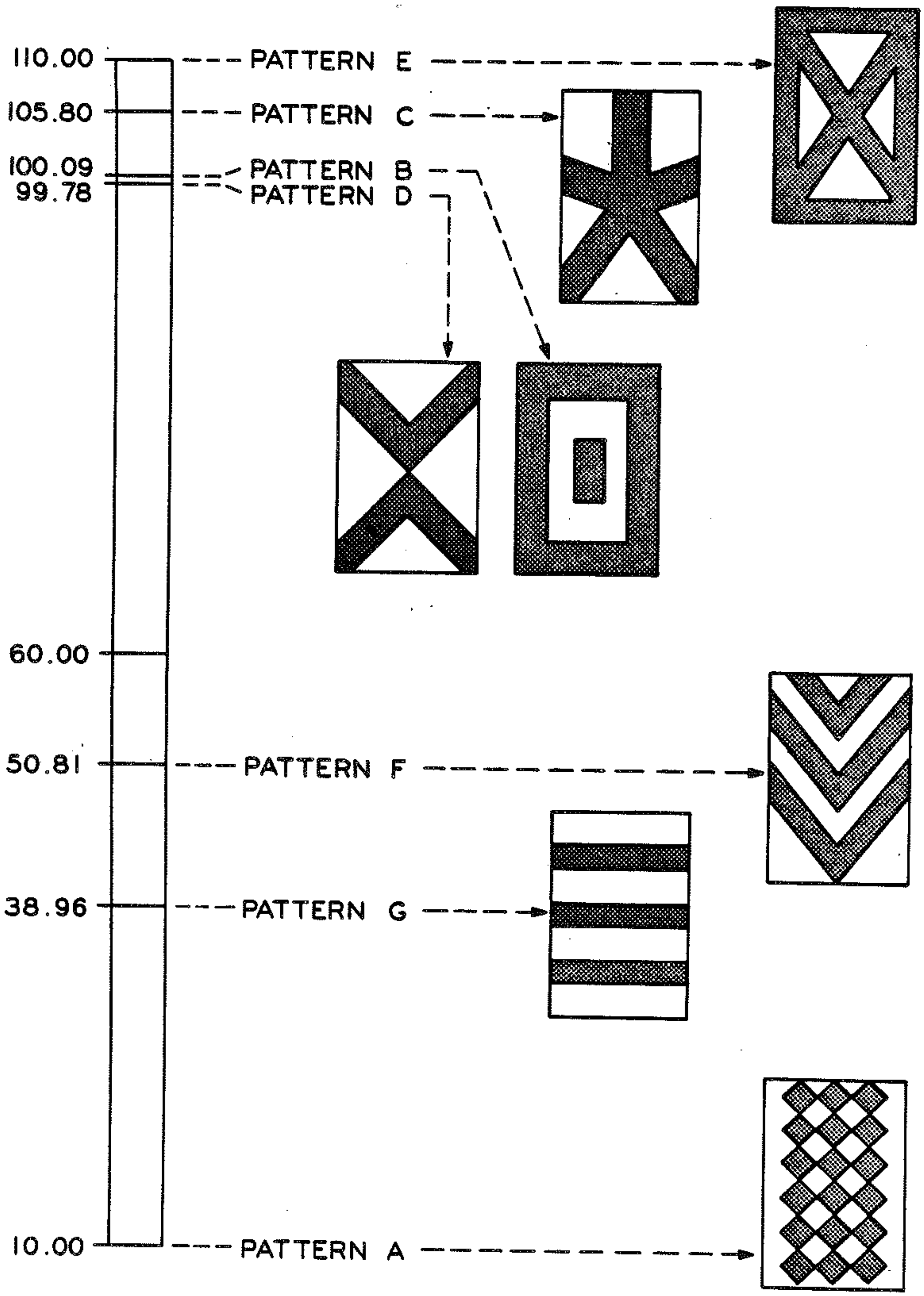

Figure 3. Scaling of pair comparison test results (Ref. 1).

fluorescent green or yellow results in still greater daytime visibility distances (7). In general, two fluorescent colors together have better visibility than the visibility of either color alone.

Fluorescent red-orange is also very effective, but is confused with other colors by most of the 7 percent of the male population that has color deficient vision.

The study of traffic regulator vests cited above (1) found that the vest color red or white was preferred to orange. Yellow was not evaluated. In a similar study (2), which included yellow and yellow-green vests, it was found that a yellow-reflectorized flagger vest pattern was superior to a silver, red, or orange reflectorized pattern at night for most viewing conditions. In the daytime, a yellow-green fluorescent pattern on a fluorescent yellow-orange vest was best with silver or fluorescent yellow on fluorescent yellow-orange close behind, all of which were much better than fluorescent red or orange on fluroescent yellow-orange.

Solomon (8) theorized that green-yellow was the best color for daylight viewing (because the eye is most sensitive to that color) and that white or silver was the best for night viewing of reflectorized material (because of high reflectivity and high contrast with dark or black surroundings).

An Institute for Perception study has shown that for daylight viewing, fluorescent orange is more conspicuous against backgrounds of most colors than other fluorescent or non-fluorescent colors (9). Fluorescent red-orange was as effective, but since it contained more red than yellow-orange, it was less visible to persons with color deficient vision. The color yellow (not fluorescent) was next in effectiveness. Fluorescent yellow proved to be so bright in sunlight that its color washed out, reducing its visibility below that of a non-fluorescent yellow.

According to Birren (10), the color yellow is conspicuous under all lighting conditions. Red loses its color under poor illumination conditions before any other color. Red, orange, and yellow give the impression they are nearer to the observer than they really are. Green and blue seem farther away, an undesirable characteristic in a vest worn by a traffic regulator. Road noise decreases the sensitivity of the human eye to red and orange, and increases it to green and blue, yellow being neutral. Therefore, in roadway conditions with traffic noise present, red or orange vests may lose some of their conspicuity, while yellow vests would retain it.

Brightness

Austin et al (4) found that for a target size in the range from 64 to 256 sq in., which encompasses the areas of the reflectorized materials used in this study, the brightness required to be "visible" at night was about 0.04 foot-Lamberts (ft-L) minimum. A target required a minimum luminance range of 0.5 to 2.0 ft-L to be "easily visible." That luminance necessary to be "attention-getting" was approximately 15 to 40 ft-L. The authors defined "attention-getting" as that attribute of a visual object which attracts the observer's attention even when the observer is not looking for the object.

Forbes (11) found that signs required increased luminance for color recognition as background luminance increased. Minimum luminance contrast between a sign and its ambient background of at least 65 percent is required for maintaining a 'minimum level of visibility' and 80 to more than 90 percent for correct color recognition of the sign. Traffic regulator vests should not only be easily visible but their color should be recognized.

Bloom (12) measured the effect the luminance and shape of a retro-reflective pedestrian target had on driver detection and recognition distances, in an essentially rural lighting environment with observers having 20/20 acuity. He found that target shape carried the larger impact of the two factors on recognition of the target and a lesser effect on detection distance, both positive correlations. Luminance had a major impact on detection distance, but a minor effect on recognition distance.

The larger the retro-reflective pedestrian target size, the more responsive were detection and recognition distances to changes in luminance; however, higher luminances reduced the recognition distance for smaller sizes of the target. Reflectorization of the entire trunk of the pedestrian was more effective than a single stripe which was, in turn, much more effective than a point source or spot.

It has been reported that detection distances measured for a driver using low beams and a pedestrian target with typical 8 to 25 percent reflectivity were 350 to 520 ft, and 30 to 200 ft with opposing headlight beams. Therefore, only with reflectorization can the luminance of a flagger vest allow it to be detected 700 ft away, the distance at which it may be assumed that the driver must be able to detect the flagger in order that a safe stopping distance is assured.

Area

As for a minimum size necessary for a flagger to be seen at night, Solomon (8) found that 232 sq in. of reflectorized area was adequate, and Michon (9) judged that approximately 200 sq in. was sufficient area for minimal attention value. An MDOT study (3) revealed that a 210 sq in. reflectorized area of the proper shape was superior to an approximately 600 sq in. rectangular area in observer preference at night.

Age of Observers

A factor not related to the vest attributes, but having a large impact on driver visual performance is age. Older drivers tend to have the lowest visual acuity and highest sensitivity to glare.

The traffic regulator vest and STOP sign must assist the driver in making a risk assessment of the roadway. Quimby and Watts (13) found that drivers in the 45 to 54 year age group, or middle age group, on the average made the highest risk assessments of roadway where the oldest and youngest made the lowest risk assessment. Risk assessment was defined as an evaluation of the amount of danger inherent in a roadway hazard. The oldest and youngest age groups of drivers tested also had greater risk-taking behavior and longer reaction time than the middle aged drivers.

RESEARCH PROCEDURE

Vest Evaluation

The vests were presented to the observers in a series of pairs such that each type of vest was compared with all of the other types of vests. Each pair of vests were spaced 4 ft apart. For each pair presentation, the observer was asked to indicate which vest he considered to be the better. The criteria for the comparison were; 1) The observers were asked the question: "Which vest would you feel safer wearing on a dark night?" and, 2) The observers were also asked to choose the better vest pattern using the criteria: visibility, conspicuity, or attention-getting, and recognizability. A 24-in. diameter STOP sign with an 8-in. legend standing at a 6-ft bottom height, typical of Michigan's practice, was located midway between the vests.

Observers chosen at random from Department employees and families ranged in age from 18 to 70 years. Because both older and younger drivers tend to make lower risk assessments of roadways, and older drivers have more visual problems, observer groups purposely included ages 55 to 70 and 18 to 35 years.

Observers were instructed not to discuss their observations with fellow observers so as not to influence their reactions. The pair presentation order was randomized for each group of 8 to 12 observers.

The observer-driver was requested to drive toward the vests at about 45 mph using low-beam headlamps and starting at a distance of approximately 1,500 ft. Observers made their choices at a 700-ft distance and again at 450 ft. Three cones on each side of the route of the observer vehicle clearly marked each of the two decision points for the observers. These distances were selected because it was judged that the driver should be able to detect the flagger before, or certainly soon after the FLAGMAN, 500 FT sign as required by the "Manual on Uniform Traffic Control Devices."

Three to four observers occupied each of three vehicles. Drivers were instructed to initiate their run after any preceding observer car was out of sight so that possible taillight effects would be eliminated. A pilot study had shown that seating position had negligible effect on observer choices.

TABLE 1
SPECIFIC BRIGHTNESS OF REFLECTORIZED FLAGGER VEST
IN CANDELA PER FOOT-CANDLE PER SQ FT

Color	Divergence Angle = 1/10°			Divergence Angle = 1/5°			Divergence Angle = 1/2°		
	Entrance Angle			Entrance Angle			Entrance Angle		
	-4°	20°	30°	-4°	20°	30°	-4°	20°	30°
Red	45.0	32.5	8.3	28.2	20.8	5.9	19.4	17.2	3.8
Orange	166	116	21.1	100	73.4	16.5	69.3	53.7	9.3
Yellow	261	195	41.6	185	132	30.0	136	94.3	16.8
Green	142	99.4	30.7	76.1	53.0	18.8	76.1	56.5	16.4
White	283	204	45.3	190	137	33.4	144	109	20.8

TABLE 2
SPECIFIC BRIGHTNESS OF STOP SIGN
IN CANDELA PER FOOT-CANDLE PER SQ FT

Color	Divergence Angle = 1/10°			Divergence Angle = 1/5°			Divergence Angle = 1/2°		
	Entrance Angle			Entrance Angle			Entrance Angle		
	-4°	20°	30°	-4°	20°	30°	-4°	20°	30°
High Level Brightness - Encapsulated Prism Reflective Sheeting									
White	1700	1200	750	730	600	475	120	100	90
Red	230	175	100	135	110	70	35	40	35
Medium Level Brightness - 'High Intensity' Encapsulated Beam Reflective Sheeting									
White	370	310	220	300	270	250	120	120	115
Low Level Brightness - Enclosed Beam (Engineering Grade) Reflective Sheeting									
White	140	120	75	125	100	65	60	55	40
Red	25	20	15	22	18	12	12	11	8

The tests were run at dusk or twilight and at night in a rural area on a two-lane roadway. There was virtually no traffic on the opposing lane during the observations. The observers were instructed to abort their run if they sighted opposing traffic. Three orange reflectorized construction signs were placed on the right shoulder at 1,000, 500, and 250 ft from the vests. The observer vehicle headlamps were aimed visually in accordance with the 1974 SAE Standard No. J599c, Lighting Inspection Code.

Reflectorized Vest Brightness

Vest brightness in foot-Lamberts was measured by a Model 1980 Pritchard Telephotometer located near the driver's eye. The following table lists the nighttime vest brightnesses for each color of reflectorized material under low-beam illumination from an automobile 450 ft from the vests. The values are averages of a minimum of six readings evenly dispersed about each vest.

Color	Brightness, ft-L
Red	4.5
Orange	13.9
Yellow	14.1
Green	4.4
Silver	14.4

The brightness values for upper-beams were roughly twice the values in the table above.

Table 1 lists the specific brightnesses of each color of reflectorized vest material used in the final series of studies. These values were determined by the Michigan Department of Transportation method for photometric testing of reflective materials in an indoor 100-ft photometric range (14), a method similar to Federal Test Method 370.

The vest brightnesses at dusk with the vests illuminated by vehicle headlamps ranged from approximately 50 ft-L to 3 ft-L.

The observations at dusk began 15 minutes before sunset. The natural illumination on the vests from the sky at dusk (measured by an International Light Research Photometer Model IL 710A), ranged from 45 to 0.25 horizontal foot-candles (ft-c). Below 0.25 ft-c at the vest, observer responses became similar to those made at night.

STOP Sign

The STOP sign positioned midway between the two vests in each pair presentation was fabricated from 0.1-in. aluminum sheet. The diameter across the flats was 24 in. The legend was 8 in. high with 1-in. stroke. A polycarbonate reflectorized material comprised the white legend and border, and red background of the STOP sign.

TABLE 3
RESULTS OF OBSERVER RESPONSES TO QUESTIONNAIRE
(Total of 71 Observers)

Question	Flagger's Vest	STOP Sign	Equal Importance	Yes	No
1. Do you think it is more important to notice the flagger's vest or the stop sign held by the flagger, or are both equally important?	18	21	32		
2. Should the flagger's vest appearance be unique?				62	9
3. Do you think that the flagger's vest should have the same appearance day as night?				54	17
4. Have you ever worked in traffic?				45	26
5. Have you ever worked as a traffic regulator?				28	43

TABLE 4
FLAGGER VEST RANK

Rank Order	Urban Lighting Environment					
	Dusk			Darkness		
	Color	Shape	Numerical Rating	Color	Shape	Numerical Rating
1	Yellow	X	76	Yellow	X	100
2	Yellow	X	67	Silver	X	80
3	Red	X	51	Red	X	66
4	Silver	X	50	Yellow	X	61
5	Silver	X	34	Green	X	57
6	Green	X	29	Red	X	44
7	Red	X	26	Green	X	44
8	Orange	X	10	Silver	X	21
9	Green	X	5	Orange	X	1
10	Orange	X	0	Orange	X	0

The reflectorized material was available in pieces no larger than a nominal 9-in. square and therefore had to be inlaid on the sign in a manner similar to floor tiling.

Table 2 shows the specific brightness of the STOP sign with the encapsulated prism reflective sheeting measured according to the Michigan Department of Transportation test method (14), and conforming in general to Federal Test Method Standard No. 370, in a 100-ft photometric range. For comparison, the specific brightness of typical white high intensity STOP sign and of enclosed bead ('engineering grade') STOP sign both white and red reflective sheeting is included. Note that for the case where the divergence angle (the angle subtended at the STOP sign by the gap between the driver's eyes and the headlamps) is 1/2 degree the brightness differences are smaller. Since the 1/5 degree divergence angle situation occurs only for short viewing distances high brightness is less necessary for conspicuity of the STOP sign.

RESULTS AND CONCLUSIONS

Observer Survey

Prior to the test runs the observers were queried regarding their work experience on the roadway and as to their opinions regarding the reflectorized vest pattern and the STOP sign. Table 3 summarizes results of responses for all observers in this study and in a previous study (3).

A plurality (32) of observers agreed that both the STOP sign and the flagger should be equally visible to the motorist. Of those preferring one or the other, a slightly greater number (21) indicated that it was more important that the driver notice the STOP sign than the flagger, with 18 preferring the reverse.

The vast majority of observers felt that the flagger's vest pattern should be unique (i.e., distinguishable from safety vests worn by other workers at the construction site) and should have the same appearance day and night.

Question No. 4 showed that most of the observers had experience as workers in roadway construction or traffic for the Department of Transportation and that 40 percent of the observers had also acted as traffic regulators at one time or another.

Nighttime

Table 4 shows the scaled results using the pair comparison method for the subject nighttime observations of side-by-side paired vests (see Appendix). The significance of the results of this method are the rank order of preference for the vests and the relative spacing between the scalar values for each vest which indicates how strongly vests are preferred over lower ranking vests. The scale values themselves are dimensionless.

Urban Lighting Environment

For the urban lighting environment evaluations, two pairs of lighted upper-beam headlamps surrounded each pair of vests that the driver-passengers viewed. The headlights of the observers' vehicle were lighted during all of the urban lighting environment evaluations.

From Table 4, it is evident that the yellow chevron's pattern is preferred by a considerable margin over other patterns. Overall color rather than shape appears to affect preferences. Shape had little or no effect even though some observers said that the double chevron pattern was much more distinct than the 'stick man' pattern.

The value of 100 for the nighttime observations of the yellow chevrons vest was arbitrarily established. All other vest ratings in Table 4 are related to this arbitrary value.

The rating for the yellow chevrons at dusk was far below the rating for the yellow chevrons at night which may indicate that there is less impact from reflectorized vests at dusk in addition to a reduced capability of observers to distinguish between colors and shapes in the diffused light.

A small survey of construction and maintenance zones was conducted by visiting the work site over a two-week period on state trunklines. The majority of the traffic regulators (approximately three out of every four) in two-way traffic situations, i.e., situations where traffic was passing through the construction or maintenance zone in two opposing directions and frequently even in one-way traffic, were noted standing obliquely with the sides of their bodies facing traffic. The flaggers maintained this was done in order to be able to monitor any traffic approaching from the direction opposite that which they were regulating, and to coordinate signals with other traffic regulators further along in the maintenance zone.

As a result of the traffic regulator survey, a further study was conducted to determine the effectiveness of oblique and side views of vests. Vest orientation angles of 45, and 90 degrees about a vertical axis were introduced in the experimental design of this final study because of empirical evidence that in actual practice few traffic regulators face traffic. Vests having side patterns were compared with vests having no side patterns. In addition, the 4-in. stroke patterns were compared with narrower, 2-in., stroke patterns. Greater STOP sign brightness (encapsulated prism) was compared with medium STOP sign (encapsulated glass bead) brightness. Lower STOP sign brightness (enclosed bead 'engineering grade' reflective sheeting) was not included because observers noted in a previous study a severe lack of conspicuity associated with the low luminance. The results, in terms of observer choices, are shown in Table 5. No Thurstone scaling (15) was applied to this additional study because of the small number (nine) of observers.

TABLE 5
OBSERVER PREFERENCE FOR VEST AND STOP SIGN COMBINATIONS
(Frontal, Oblique, and Side Views)

Stripes on Side of Vest	Vest Pattern Stroke Width	STOP Sign Luminance[1]	Flagger Orientation Angle, degrees[2]	Percent of Observer Choices			
				Dusk		Dark	
				700 ft	450 ft	700 ft	450 ft
Yes	2 inch	Medium	0	48	37	33	30
Yes	2 inch	High	0	78	78	56	56
Yes	2 inch	Medium	45	17	25	33	47
Yes	2 inch	High	45	—	—	39	39
Yes	2 inch	Medium	90	3	8	3	11
Yes	2 inch	High	90	—	—	—	—
Yes	4 inch	Medium	0	39	22	67	78
Yes	4 inch	High	0	56	78	67	78
Yes	4 inch	Medium	45	50	49	49	17
Yes	4 inch	High	45	61	67	67	72
Yes	4 inch	Medium	90	33	11	22	22
Yes	4 inch	High	90	72	72	56	50
No	4 inch	High	0	22	78	11	33
No	4 inch	High	45	33	44	28	33
No	4 inch	High	90	33	44	11	11

1. Medium: STOP sign coated with encapsulated bead reflective sheeting ('high intensity').
   High: STOP sign coated with encapsulated prism reflective sheeting.
2. 0° - Flagger facing motorists.
   45° - Flagger facing at an oblique angle to roadway.
   90° - Flagger facing in direction transverse to road (shoulders parallel to roadway).

In a preliminary study in an indoor photometric range, five observers evaluated four different scaled-down designs for reflectorized patterns for the side panel of the vest in order to reduce the number of side panel designs and observer choices in the full-scale study described above where vests combining front and side panel designs were compared. Each shape was compared with each of the other three shapes with the vest oriented at 0, 45, and 90 degrees with respect to the observer.

The four side pattern shapes employed in the preliminary study were: a vertical stripe, two horizontal stripes, two diamonds, and chevron standing on end. The observers preferred the horizontal stripes by a small margin over the chevron standing on end. The vertical stripe finished last in preference. Therefore, the only side pattern design used in full-scale study was two horizontal stripes or blocks on the side of the vest.

While the results (Table 5) were variable because of the paucity of observers, they did show some trends in preference as follows:

1) At night, reflectorized stripes on the side of the vest were preferred to the absence of stripes, less so during dusk.

2) A 4-in. wide stroke side pattern was preferred to a 2-in. wide stroke side pattern in the 90-degree orientation where the driver was viewing a side of the traffic regulator. A high luminance (encapsulated prism) STOP sign was necessary in addition to a 4-in. wide stroke in order to obtain the level of observer response that frontal orientations attained.

3) A narrow stroke frontal pattern (0-degree orientation) was approximately equal in preference to a wider stroke frontal pattern during dusk and dark.

4) The high brightness STOP sign was greatly preferred to the medium brightness sign in combination with any vest pattern at each orientation angle except the 2-in. wide stroke patterned vest at 45 degrees, at night, at 450 ft, and the 4-in. wide stroke pattern, at night and 0-degree orientation.

5) Observers did not show as much preference at night for the brighter STOP sign as they did during dusk. Several observers remarked that the brighter STOP sign halated at night which made it more difficult to read and less recognizable as the familar octagonal shape. The high brightness of the STOP sign also reduced the saturation of color intensity of the red areas of the sign. Color is at least as important a factor as the word STOP in identification of the sign by drivers.

Color

In the daytime, the luminance of the background against which a vest must be seen may typically reach as much as 3,000 ft-L. The luminance of a vest with the same color as its background must be approximately 30,000 to 45,000 ft-L to be readily seen against daytime backgrounds with typical luminances. Values of 3,500 to 4,500 ft-L (depending on direction) were measured for a fluorescent blaze orange vest on a sunny day with a cloudless sky, and about 1,500 ft-L for the same vest on a cloudy day, not enough for the vest to be easily seen if it were the same color as its background. Typically, however, the color of a fluorescent flagger vest, blaze orange, is in strong contrast to the color of its background (20 percent green, 40 percent gray, etc.(11)), except when it is positioned in front of a Departmental vehicle painted FHWA Transportation Orange. Since positioning of a traffic regulator in front of a vehicle of orange color is a distinct possibility on maintenance or construction road projects, visibility of the vest worn by the traffic regulator must be enhanced.

Addition of a fluorescent yellow pattern to the fluorescent orange vest will increase the visibility distance and its contrast with an orange background. For slightly greater impact, the pattern may be yellow-green instead of yellow.

Observers viewed in daylight the fluorescent yellow chevrons-on-fluorescent-yellow-orange-mesh-background vest compared with a plain orange vest. Observers agreed that the yellow stripes increased the visibility and conspicuity of the plain fluorescent orange mesh vest because the yellow contrasted highly with the orange background and because the solid vinyl yellow material exhibited much greater reflectivity than did the open mesh fluorescent orange vest material.

A further reason for using yellow as the color of the reflectorized pattern on the vest is that color-blind people, who constitute about 7 percent of the male and 0.4 percent of the female population, have almost as much sensitivity to yellow as do persons with normal vision, although people with defects in color vision may confuse yellow with red and green. Two-thirds of these people have practically the same sensitivity to the luminosity of all colors as does the normal observer, and though they may confuse yellows with reds and greens, they will still perceive yellow as being lighter or brighter than reds and greens as does the color-normal person. The other third are practically insensitive to red; thus, the use of a red traffic regulator vest would render the vest very difficult to see by 2.2 percent of the male population. Of course, a STOP sign held by a flagger would also appear dark and difficult to detect at a distance (except for the white legend and border) to these persons. Given that the STOP sign must be red, then the flagger vest should be a color which appears bright to observers with color-deficient vision. Yellow is generally the brightest color perceived by visually color-deficient observers.

The use of a yellow material for the vest pattern which is both fluorescent and reflectorized, and therefore easily visible day and night, should meet the implied intent of the current "Manual on Uniform Traffic Control Devices" which is that the day and nighttime colors of the vest should be similar. The remainder of the vest area not covered by the fluorescent/reflectorized yellow pattern should be orange in conformance with the "Federal Manual on Uniform Traffic Control Devices." For greater daytime visibility this orange portion of the vest should be fluorescent.

The yellow contrasts best of all colors evaluated with the currently recognized color code of the standard traffic regulator vest, viz, fluorescent orange which confirms previous research showing that a fluorescent yellow and orange combination can be seen much farther than either fluorescent yellow or orange alone.

Transportation Orange has very low chromatic purity, a characteristic of color appearance which results in a very dull appearing orange which is truly a 'brown' color. The color brown has an extremely low visibility and conspicuity attached to it. Research has demonstrated that low purity colors, i.e., colors which are not highly saturated, have poor visibility. Saturated colors have a very low proportion of gray mixed with them. An example of highly saturated colors are the colors of the rainbow.

Other than orange, the vest colors evaluated (red, yellow, green) were relatively saturated. Silver or white is usually considered to be devoid of color and is actually a combination of all colors.

Nighttime Pattern Shape

The majority of observers preferred the pattern shape in Figure 1B, a chevron pattern over an inverted chevron pattern. Reflectorization over the entire trunk of the flagger is not only unnecessary for recognition and visibility of the flagger, but it is impractical in that well over half of the reflectorized area must be removed for adequate cooling of the wearer. Reduction of the reflectorized area to this extent would reduce the effectiveness to well below that of other pattern shapes evaluated.

The humanoid pattern (Fig. 1A) was highly ranked by observers, but several observers remarked that the upper portion of the humanoid pattern was indistinct because it was too 'busy' or was comprised of too many appendages. The chevron-over-inverted-chevron pattern, or 'X' shaped pattern, removed some of this ambiquity of shape according to some observers.

Even with the two 4 by 4-in reflectorized patterns on the vest side panel, very few observers saw the traffic regulator or the STOP sign when the traffic regulator was standing sideways to traffic, unless the STOP sign was coated with the brightest material used in this study, the polycarbonate plastic sheet incorporating encapsulated prisms. Therefore, there is a risk that the flagger will not be seen by the driver unless the STOP sign is bright enough.

Under Adverse Weather Conditions

The progress report on flagger vests (3) demonstrated that in fog at night, and perhaps in severe weather conditions, the three shapes of the reflectorized pattern evaluated had slightly less impact than did a fully reflectorized vest with approximately three times the reflectorized area of each of the three shapes. The fully reflectorized vest was chosen as best in fog by observers. The vests with shape to their pattern could not be seen as far away. Where the vests could be seen, the pattern shape could not be distinguished. Therefore, luminance and size, rather than recognizable shape of the reflectorized pattern probably carries the greatest impact under circumstances of extremely low atmospheric transmission such as fog, or very heavy rainfall. Casual observations of reflectorized vests during normal rainfall showed that shape could be easily discerned.

Brightness

These tests were conducted using the brightest known fabric materials. The Progress Report showed that there were large differences between the preferences (nearly a 2 to 1 ratio) for a vest with a brightness equivalent to the brightness of the vests in this series over a vest with 2/3 the brightness, and over a vest with 1/3 the brightness (approximately 10 to 1) (3). Because of the observers' very strong preference for vest brightness at the highest levels used in this report, it may be that still higher levels, if available, would be preferred; however, drivers may not notice the STOP sign at those higher levels of vest brightness. Indeed, in the study reported in the Progress Report, many observers had not noticed the STOP sign located between the pair of vests (3). That STOP sign was faced with low brightness 'engineering grade' enclosed bead reflective sheeting.

In this study, the STOP sign preferred by observers was faced with a polycarbonate material comprised of encapsulated microprisms which had approximately 10 times the reflectivity of engineering grade reflective sheeting. The STOP sign coated with encapsulated bead (high intensity) reflective sheeting was not as strongly preferred by the observers, yet nevertheless was noticed by the observers. Therefore, the brightness of the STOP sign should be on a par with, or better yet, exceed the brightness of the vest.

It was judged that evaluation of an internally illuminated STOP sign was not necessary since the brightness of the STOP sign coated with the encapsulated prism material was adequate to compete with the vests for the driver's attention. Moreover, several observers mentioned that at night, while it was bright enough to be visible and recognizable from its red color and octagonal shape, it was too bright to be easily read. From the observers' description, it was judged that what they were referring to was the halation of the white STOP legend. Loss of legibility of a STOP sign may not be significant since research has demonstrated that motorists obeyance of such signs is related to shape and color rather than legend, as long as the STOP sign was sufficiently bright.

If materials for reflectorizing vests are found which are brighter than the vests used for this study, an investigation should be conducted to determine whether the encapsulated prism coated STOP sign is noticeable in proximity to a brighter vest than the vests employed in this study.

There are indications that it is possible to manufacture brighter vest materials than those employed in this study, but at the levels of vest brightness used in this study, some observers remarked that the vest pattern at 700 ft was indistinct because the shape of the pattern was 'blurry.' Apparently there was halation caused by the high brightness of the vest material. This phenomenon did not occur where the vests were viewed against on-coming headlights, probably because the observers' vision was adapted to higher levels of illumination at their eyes.

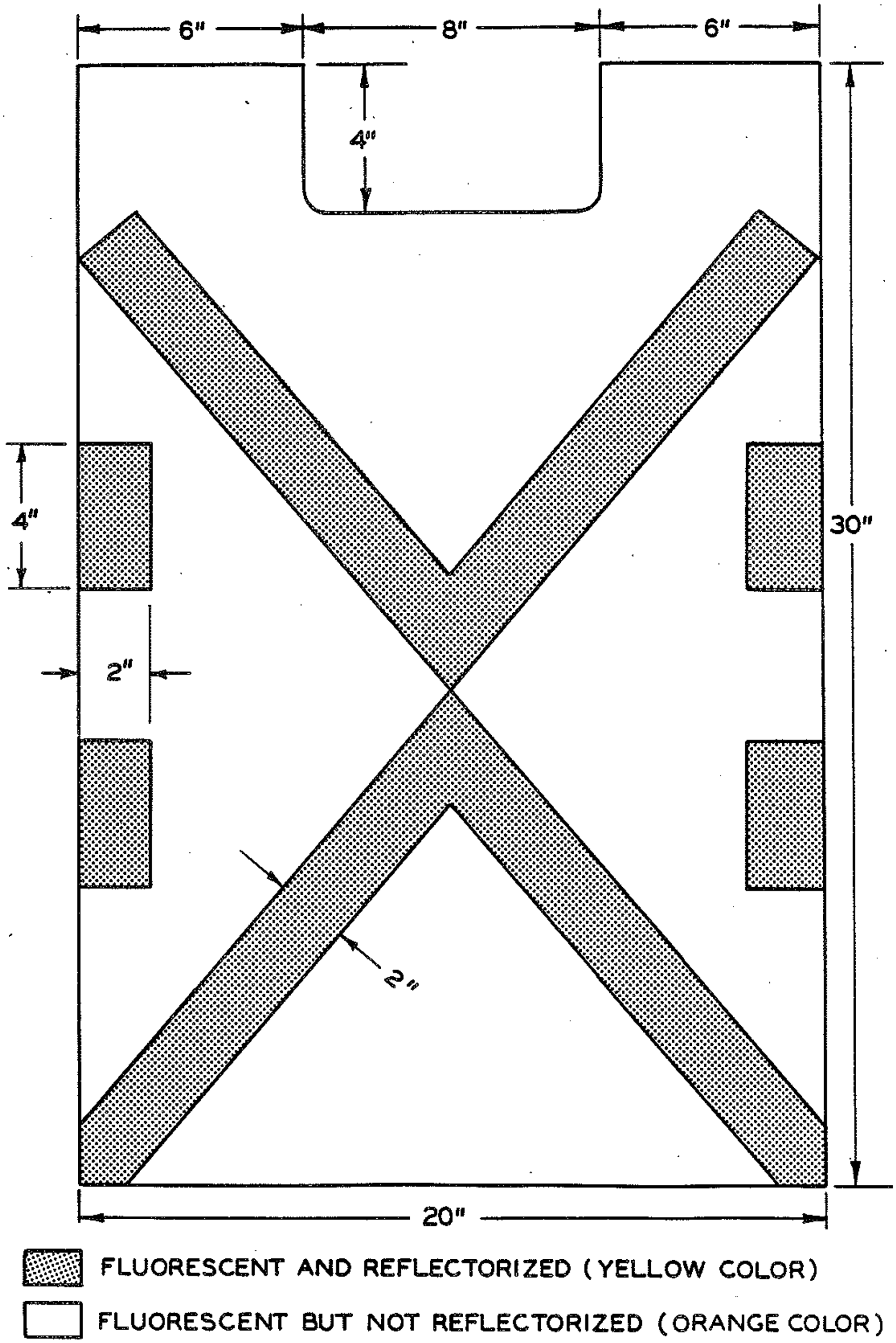

Figure 4. Recommended reflectorized vest pattern for front and back panels.

Additional Reflectorization

It is advantageous to outline the vest in reflective stripes or piping in addition to the reflectorized chevron pattern so that the entire trunk of the flagger would be profiled for greater visibility and recognizability. Our first flagger study (1) found that such a pattern was ranked first by observers by a small margin over both the 'stick man' pattern and the currently recommended chevron pattern. This option was discarded in later comparisons because of acknowledged much greater expense for only a slight improvement in visibility.

Subjective comments by observers after viewing flaggers with and without reflectorized paraphernalia, in addition to the vest (such as gauntlets, leglets, and striped hardhat), indicated that the reflectorized accessories were a vast improvement, largely because those items which were located at the extremities of the flagger's limbs, moved.

SUMMARY OF RECOMMENDATIONS

Shape

1) The shape of the pattern should be an inverted chevron underneath a chevron (see Fig. 4 for specification). This shape provides reflectorization for the corners of the trunk of the flagger with less ambiguity than the 'stick man' shape previously recommended (1), while still conveying a quasi-anthropomorphic figure (with apparent arms upraised as some observers have described it) which may assist the driver in identification of the flagger. This pattern should not be achieved by crossing two rectangles because excessive halation visible to observers occurs in the region where the rectangles cross resulting in an unacceptable loss in pattern definition. The side pattern should consist of two 4 by 4-in. squares on each side of the vest to be formed by the joining of two 4 by 2-in. rectangles on the front and back vest panels (Fig. 4).

2) The stroke width of the frontal pattern can be as narrow as 2 in. A 2-in. stroke width allows adequate mesh area for cooling, a characteristic highly desired by most flaggers and results in a reduced cost of material, while still providing reflectivity and recognition for the frontal pattern portion of the vest which elicited sufficient favorable observer response.

Color

Nighttime - The color should be yellow (for the reflectorized portion of the vest). Orange may be used in conformance with the Federal Manual, but it should be recognized that observers consider transportation orange vastly inferior to yellow, red, and white, and most consider orange inferior even to green, within the lighting environment parameters used in this study.

Daytime - Yellow pattern on fluorescent "Blaze" yellow-orange mesh fabric vest. The yellow may be fluorescent but is not absolutely necessary, because fluorescent yellow is only slightly superior in visibility to non-fluorescent yellow. For slightly greater visibility the pattern color may be yellow-green instead of yellow.

Brightness

Vest - The specific brightness of the vest pattern should be a minimum of 170 cd/ft-c/sq ft at 1/5 degree divergence and -4 degree entrance angles when measured in accordance with Federal Photometric Test Method No. 370, which would provide a nighttime brightness under lower beam headlamp illumination of approximately 15 ft-L at 400 ft. A brightness of 15 ft-L is the minimum brightness that would provide the "attention-getting" level of visibility found by Austin et al (4). Ideally, the brightness should be still greater, but at this time there is no reflectorized fabric material known which is capable of providing significantly higher brightnesses.

STOP Sign - The STOP sign should be coated with a reflectorized sheeting material which has an equal or higher reflectivity than the vest; i.e., the luminance of the STOP sign legend should be equal to or greater than the reflectorized portion of the vest under headlamp illumination. Low luminance reflective material such as enclosed bead ('engineering grade') reflective sheeting should not be used.

The preferred brightness of the STOP sign is greater than that normally provided by encapsulated reflective sheeting, such as 'high intensity' reflective sheeting. However, should factors of availability or cost arise in connection with encapsulated prism material then encapsulated bead material (high intensity) is barely adequate. At this time, only encapsulated prism material is capable of this level of luminance.

Should higher brightness vest materials than recommended here become available, the STOP sign brightness should be raised still higher than the level of which encapsulated prism material is capable.

Still greater brightness could be attained by means of internal illumination of the STOP sign which could be provided by fluorescent lamps housed in a case sign powered by batteries located in the handle. Internal illumination of the STOP sign should not be employed with the brightest known vest materials because halation might cause its octagonal shape to appear amorphous to an observer, a condition ensuing from excessive brightness. The octagonal shape is essential to the distant identification of the STOP sign by motorists.

Field Trials - Field trials of reflectorized-fluorescent vest material as well as of the STOP sign reflective material should be conducted. In addition, a combination of reflectorized gauntlets, leglets, and hardhat may be worn by traffic regulators for the trials in order to assess their effectiveness.

REFERENCES

1. Janson, M. H., and Smith, G. M., "Reflectorization of Fluorescent Flagman Vests," Michigan Department of Transportation, Research Report R-873, July 1973.

2. Smith, G. M., and Janson, M. H., "Reflectorized Flagman Vests," Michigan Department of Transportation, Research Report R-1021, September 1976..

3. Janson, M. H., Smith, G. M., and Truax, J. D., "Reflectorized Traffic Regulator Vests (Progress Report)," Michigan Department of Transportation, Research Report R-1135, April 1980.

4. Austin, R. L., Klassen, D. J., and Vanstrum, R. C., "Pedestrian Conspicuity Under the Standard Headlight System Related to Driver Perception," Unpublished 3M Co. report.

5. Blomberg, R. D., Hale, A., and Kearney, E. F., "Development of Model Regulations for Pedestrian Safety," U. S. Department of Transportation, Report No. DOT-HS-801-287, November 1974.

6. Harkness, K. A., <u>Effective Approaches to Reducing Accidents Involving Slow Vehicles on Highways</u>, National Safety Council, May 1964.

7. Hanson, D. R., and Dickson, A. D., "Significant Visual Properties of Some Fluorescent Pigments," Highway Research Board Record No. 49, 1963.

8. Solomon, S. S., "Visibility of Firefighters," Journal of the American Optometric Association, Vol. 45, No. 2, February 1974.

9. Michon, J. A., et al, "Safety Clothing for Human Traffic Obstacles," Ergonomics, Vol. 12, No. 1, 1969, pp. 61-70.

10. Birren, F., <u>Color Psychology and Color Therapy</u>, McGraw-Hill Co., New York, 1950.

11. Forbes, T. W., "Luminance and Contrast for Sign Legibility and Color Recognition," Transportation Research Board Bulletin No. 611, 1977.

12. Bloom, R. F., <u>Effectiveness of Retroreflective Treatments for Pedestrians</u>, Dunlap and Assoc., Inc., Darien, Connecticut, April 1976.

13. Quimby, A. R., and Watts, G. R., "Human Factors and Driving Performance," Transport and Road Research Laboratory, Report No. LR-1004.

14. Janson, M. H., and Smith, G. M., "Photometric Test for Reflex Reflective Materials," Michigan Department of Transportation, Research Report R-785, May 1972 (and Supplement, 1980).

15. Fisher, E. S., and Holbrook, L. F., "Thurscale: Thurstone Scaling on the CDC 6500," Michigan State University, Technical Report No. 20.

APPENDIX

SCALING TECHNIQUE

For each of the $\underline{T\ (T - 1)}$ pair comparison, there will be X panel members who feel that one flagger vest design (say, A) performs best of the pair, and N - X panel members who prefer the other (say, B). Thus, $\underline{X}$ and $\underline{N - X}$ are the proportions of panel members preferring vest pattern A over B, and B over A, respectively. These $\underline{T\ (T - 1)}$ proportions form a T by T matrix, P. Because the observers will disagree on the exact performance value of each vest design, it is assumed that the population scale of vest designs is such that each is distributed about a mean value designated as the scale value (S). Further, if it can be assumed that these distributions are normal with common variance σ , the P matrix can be transformed to a Z matrix by use of a table of normal deviates (Fig. A-1). For example, if 50 percent of the panel preferred A to B, and 50 percent B to A, the distribution of vest pattern scale values is assumed to be similar to that shown in Figure A-2.

In this case, the points A and B would coincide on the scale. If, however, the proportion preferring A to B was 80 percent, the presumed distribution of preferences would be similar to the one shown in Figure A-3.

The shaded area of the normal curve represents the 20 percent who prefer B to A, while the unshaded part represents the 80 percent who prefer A to B. The midpoint (or for our purposes, the arithmetic mean) of this distribution is not located at zero, but at some distance (Z) away. A proportion of 0.80 corresponds to a Z of +0.6903 for a normal distribution of unit variance. (As long as the variances of the individual stimuli are equal, the exact value is of no concern since there will always be a linear transformation of the scale which corresponds to stimulus distributions of unit variance.)

It is this Z matrix which serves as the basis for Thurstone scaling.*

---

*Usually the columns of the Z matrix are summed (if the matrix is complete with no 0.0 or 1.0 proportions). The sums are then accumulated to build the scale.

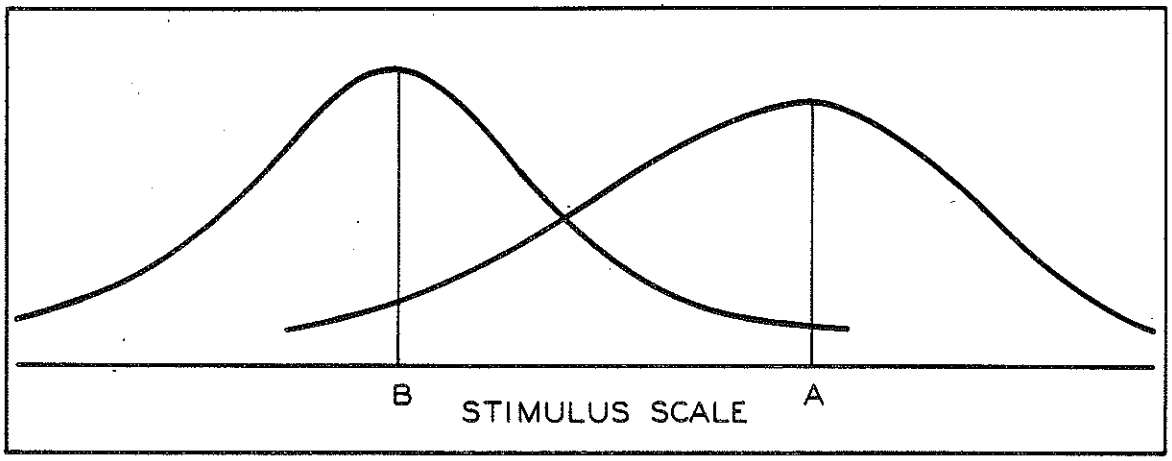

Figure A-1. Population scale values of stimuli A and B.

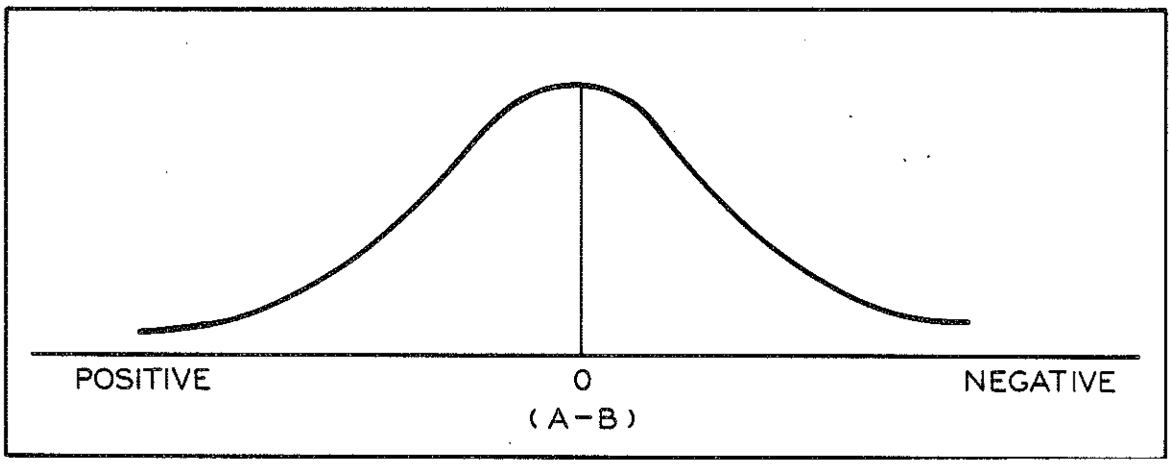

Figure A-2. Distribution of individual scale difference (A-B) where A is preferred to B by 50 percent of the panel.

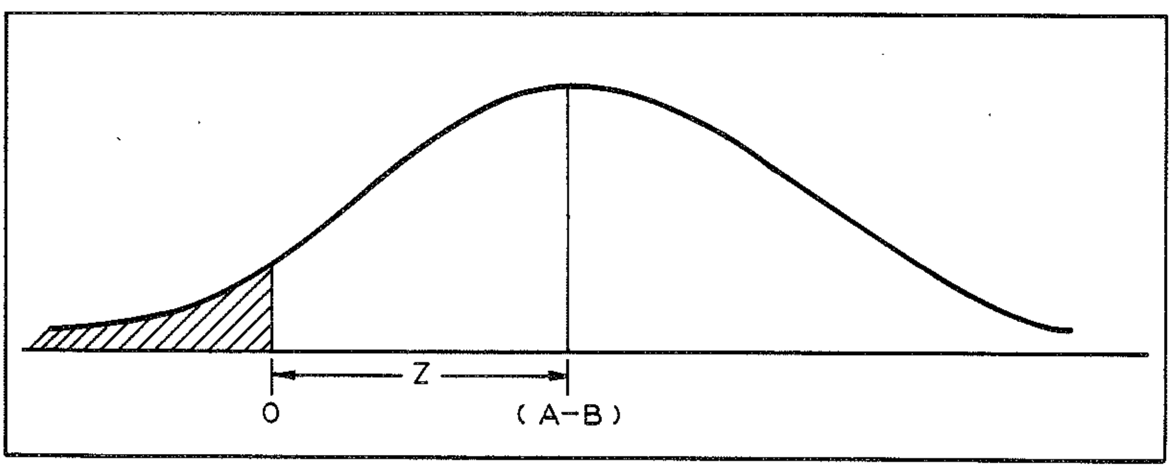

Figure A-3. Distribution of individual scale difference (A-B) where A is preferred to B by 80 percent of the panel.