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Instrumental Color Measurement of Retroreflective Highway Sign Materials

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Final Report

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16. Abstract

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A discussion of the research necessary to develop instrumental techniques for the measurement of the color of retroreflective materials under nighttime viewing conditions is also included. ( )

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OUTLINE

PREFACE

This report contains the results of a study of the colorimetric properties of retroreflective sheeting materials used for highway signs as evaluated under several conditions of illuminating and viewing geometry. At the request of the Federal Highway Administration of the Department of Transportation, the National Bureau of Standards conducted this study to develop, if possible, an instrumental procedure by which to specify and measure colors of these materials. The opinions, findings, and conclusions contained in this report are those of the author and are not necessarily those of the Federal Highway Administration. Certain commercial equipment, instruments or materials are identified in this report in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Instrumental Color Measurement
of Retroreflective Highway Sign Materials

ABSTRACT

The colorimetric properties of seventy-four samples of retroreflective highway sign materials were obtained at NBS by visual measurements outdoors using five observers having normal color vision, and by three photoelectric tristimulus colorimeters and a recording spectrophotometer. Cooperative measurements by two industrial color laboratories are also reported. The results obtained indicate that measurements made with five colorimeters having 45°,0° geometry are in general agreement. Measurements made with five instruments having diffuse illumination and unidirectional viewing geometry are also in general agreement; in addition, these measurements agree more closely with the visual color evaluations than those made with the 45°,0° geometry instruments.

A discussion of the research necessary to develop instrumental techniques for the measurement of the color of retroreflective materials under nighttime viewing conditions is also included.

I. INTRODUCTION

Highway signs and demarcations are frequently marked with retroreflective materials. Theoretically perfect retroreflecting materials reflect all of the unabsorbed light back along a direction that is opposite to that of the incident light. Consequently, any measurement of retroreflectively returned light should be measured along that direction. In general, however, retroreflective sheeting materials are not perfectly retroreflective, but reflect light in a distributive manner about the retroreflective direction. In the daytime they are observed by the driver under diffuse illumination and at night they are illuminated by the automobile's headlights and viewed by the driver seated behind the source.

For the Interstate Highway System four colors are used for these materials: red, yellow, green, and blue. The measurement of the color for compliance with the color and color tolerance of a particular batch of materials is done visually. For nighttime use the arrangement of the light source, reflector, and viewer requires that measurement and specification of the reflective properties of these materials be made at conditions of unidirectional illumination with varying incidence angle and small divergence angle viewing. The incidence angle usually is less than 10° from the perpendicular to the sign at distances greater than 300 feet. The color tolerance charts (PB-169 553, Color Tolerance Charts, available from the National Technical Information

Service, Department of Commerce, Springfield, Virginia 22151) of the Bureau of Public Roads, now the Federal Highway Administration, are used in the evaluation of the color of these materials. These charts state that, "Color comparisons shall be made under north daylight or scientific daylight having color temperature of from 6500° to 7500° Kelvin. Color shall be illuminated at 90° and viewed at 45° or the exact opposite of these conditions." (These conditions are usually designated 0°,45° and 45°,0°, respectively.) The charts state further that, "Conventional color measuring instruments such as spectrophotometers and tristimulus photoelectric colorimeters should not be used for measurement of retroreflective materials. Such materials should be evaluated visually using the Color Tolerance Charts and paying strict attention to prescribed illuminating conditions."

Federal Specification L-S-300A, dated January 7, 1970, for reflective sheeting and tape materials used for general purposes, on the other hand, states in paragraph 4.4.8 Color,

> "Determine the color of the reflective material in accordance with ASTM-E-97-55 (Geometric characteristics must be confined to illumination incident within 10 deg. of, and centered about, a direction of 45 deg of, and centered about, the perpendicular to the test surface. Conditions of illumination and observation must not be interchanged.) The standards for calibrating the test apparatus shall be the Munsell Papers designated in table I. They must be recently calibrated on a

spectrophotometer. The test instrument shall be one of the following:

1. Gardner Multipurpose Reflectometer.
2. Gardner Model AC-2a Color Difference Meter.
3. Meeco Model V Colormaster.
4. Hunterlab D25 Color Difference Meter."

At the request of the Office of Traffic Operations through the Office of Research of the Federal Highway Administration, the Office of Colorimetry of the National Bureau of Standards was asked to conduct a research study of the color measurement and specification of retroreflective highway sign sheeting materials. The objective of this study was to develop an acceptable instrumental procedure to quantitatively measure the color by means of CIE tristimulus data of retroreflective sign sheeting materials representing the four standard colors now in highway use.

A contract, dated December 8, 1970, Purchase Order No. 1-1-0929, states the various tasks required to achieve this objective:

ARTICLE I - Statement of Work

1. Theoretical and practical evaluation of the technical validity or invalidity utilizing ASTM Method E 97 and tri-stimulus colorimeters based on 45°- 0°, 0°-45° or any unidirectional illumination and uni-directional viewing geometry to define and specify the diffuse daylight color of retroreflectiorized sign sheeting repre-

sentative of the four Interstate standard colors. Cognizance shall also be taken of the following ASTM test methods and recommended practices: D 1535, D 1729, and E 308.

2. Collect a full range of samples of retroreflective sign sheeting materials that represent all manufacturers and that represent as much as possible the full color ranges of each of the four Interstate standard colors. This should include all types of reflectorization that are utilized regularly.

3. Make a visual examination and evaluation of the conformity of these samples to the Highway Color Tolerance Charts for Yellow, Green, Red, and Blue. Make instrumental evaluation of color by using the colorimetric instruments now at NBS and determine which of these instruments gives results that best correlate with the visual evaluation. Such instruments shall include the Colormaster and Color Eye Colorimeters, G. E. and Cary Spectrophotometers, and Gaertner Goniophotometer. Preliminary theoretical considerations led us to expect that color measuring instruments that have geometry that is most similar to the diffuse illumination of daylight will yield the best correlation with visual evaluations.

4. Develop, if possible, an instrumental procedure that can be practically obtained and used by a State highway department to define and specify the color of the above materials that is technically sound and compatible with present CIE limits now expressed in the BPR Color Tolerance Charts of June 1965. Measure materials obtained under item 2, above.

5. Make recommendations on the instrumental measurement (or the type of research needed to develop such measurements) of the color of retroreflective sign materials when illuminated and viewed under nighttime driving conditions.

II. THE STUDY

A. REVIEW OF ASTM COLOR MEASUREMENT METHODS

There was a suggestion made in the aforementioned contract that the following ASTM methods of color measurement be reviewed for evaluation of their application to this problem:

1. E97: Instrumental method of test for 45°,0° directional reflectance of opaque specimens by filter photometry.
2. D1535: Visual method for specifying color by the Munsell system.
3. D1729: Visual evaluation of the color difference of opaque materials.
4. E308: Spectrophotometry and description of color in the CIE 1931 system.

Colorimetric procedures, particularly those described in the ASTM methods listed above, while not specifically developed for color measurement of retroflective materials, can be used to make some measure of the color of engineering grade retroreflective sheeting materials. For instance, ASTM E97 describes a color measurement procedure under geometry of 45° incidence and perpendicular viewing that is being used by the Kentucky and the Oklahoma State road commissions to measure the color of retroreflective materials. However, because 45°,0° geometry does not simulate the conditions under which these materials are seen in daylight, the results obtained by this procedure may not be directly applicable.

In ASTM methods D1535 and D1729 are described visual methods for evaluating color and color difference under conditions of unidirectional illumination and unidirectional viewing. Because these methods, also, do not simulate the geometry of daytime conditions for retroreflective materials, they too may produce misleading results in color measurement.

ASTM methods E308, as well as its predecessors, D307 and D791, while not specifically written for retroreflective materials, are spectrophotometric procedures to measure color which do permit geometries that can simulate daytime conditions for retroreflective materials. Such a procedure is especially applicable when the test materials are diffusely illuminated and unidirectionally viewed.

B. SAMPLES

At the outset, it was agreed that the National Bureau of Standards would solicit as wide a variety of samples of engineering grade retroreflective sign materials in Highway colors, red, yellow, green, and blue, as are available from manufacturers of these materials. On January 6, 1971, we received from the Federal Highway Administration, a list of such manufacturers. They were requested, by letter, to supply the National Bureau of Standards with suitable samples. Samples of current manufacture were received from the Minnesota Mining and Manufacturing Company and from the American Decal and Manufacturing Company. The other manufacturers in the list indicated that currently they do not manufacture engineering grade retroflective materials for highway signs.

On request, the Kentucky Department of Highways graciously lent the National Bureau of Standards the samples that they used in their investigation of retroreflective highway sign materials, the results of which appeared in their report, "Development of Specifications for Retro-Reflective Materials," KYHPR-65-37; HPR-1(6), Part II, October 1970, by R. L. Rizenbergs. Of their samples, dated from 1963 to 1970, only those of most recent dates, 1970, 1969, and 1968, were used.

C. TASKS

1. Work at NBS

The tasks of this study were divided into three groups according to the types of measurements involved. These types were: photometric (photoelectric tristimulus colorimeters), spectrophotometric; and visual. In general, the tasks were performed in accord with the techniques described in the pertinent ASTM methods of color measurement.

a. Visual Observations

All were made outdoors when weather permitted. Five observers known to have normal color vision made the observations. Sometimes the weather was sunny, sometimes it was overcast. The position of the specimens and the observers was such that direct illumination from the sun, that which would produce specular reflection at the observer's eyes, was minimized. The specimens were illuminated by skylight and viewed nearly perpendicularly. Comparisons were made with the Highway Color Tolerance Charts supplied by personnel of the Department of Transportation.

b. Spectrophotometric Measurements

A Cary spectrophotometer with diffuse illumination with viewing at 8° from the perpendicular was used.

c. Photometric Measurements

Three photoelectric tristimulus colorimeters were used. Two of these, a Hunter Color and Color Difference Meter and a Colormaster Colorimeter have 45°,0° geometry. The third of these, a Color Eye Colorimeter, has diffuse illumination and viewing at 35° from the specimen perpendicular.

d. Goniophotometric Measurements

As there were no difficulties involved

in the color measurement that needed to be explained by goniophotometric distribution of reflected light, no goniophotometric measures were made.

2. Cooperative Work

An offer of cooperation was made by representatives of the 3M Company to measure the color of some of the samples on their instruments, Colormaster Colorimeters, and Color Eye Colorimeters. An offer of cooperation was made also by the Kollmorgen Company to measure the color of some of the samples of their KCS-40 colorimeter. This instrument has geometry of diffuse illumination and viewing at 8° from the perpendicular to the specimen. Other geometric arrangements are possible on this instrument.

D. STANDARDS

Unreflectorized standards, or comparison colors, for the visual and photoelectric measurements were calibrated for reflectance relative to magnesium oxide. Tristimulus values for the standards, suitable for each of the methods used, were obtained by computation from the spectrophotometric data. From these tristimulus values of the standards the chromaticity coordinates were computed by means of the applicable transformation equations. These chromaticity coordinates are shown in Figures 1, 2, 3, and 4 for the red, yellow, green, and blue standards, respectively.

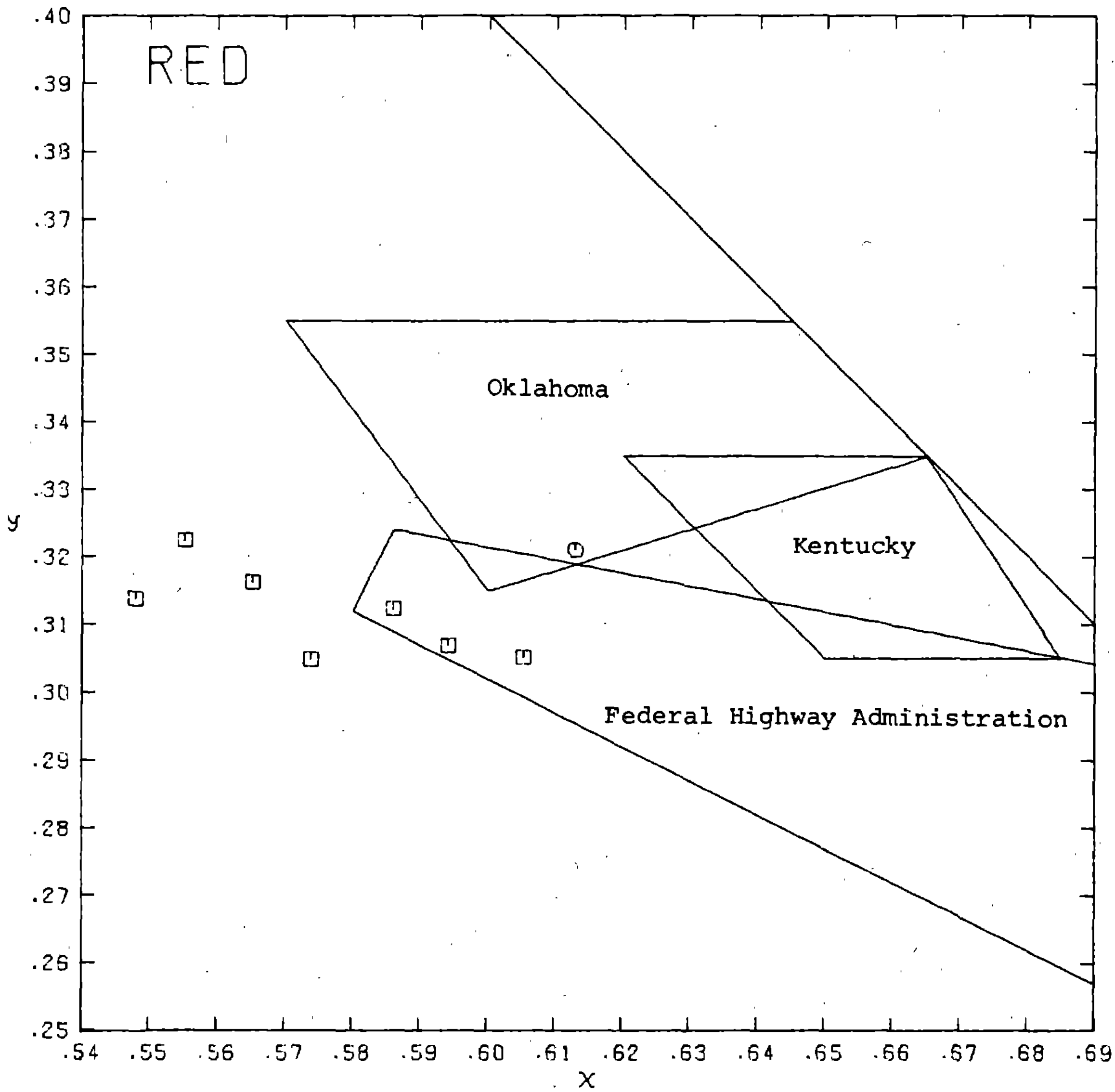

Figure 1. Chromaticity coordinates of various tolerance regions and the standards used in the:
□, visual measurements,
○, photoelectric measurements.
The chromaticity coordinates of the standards were spectrophotometrically derived.

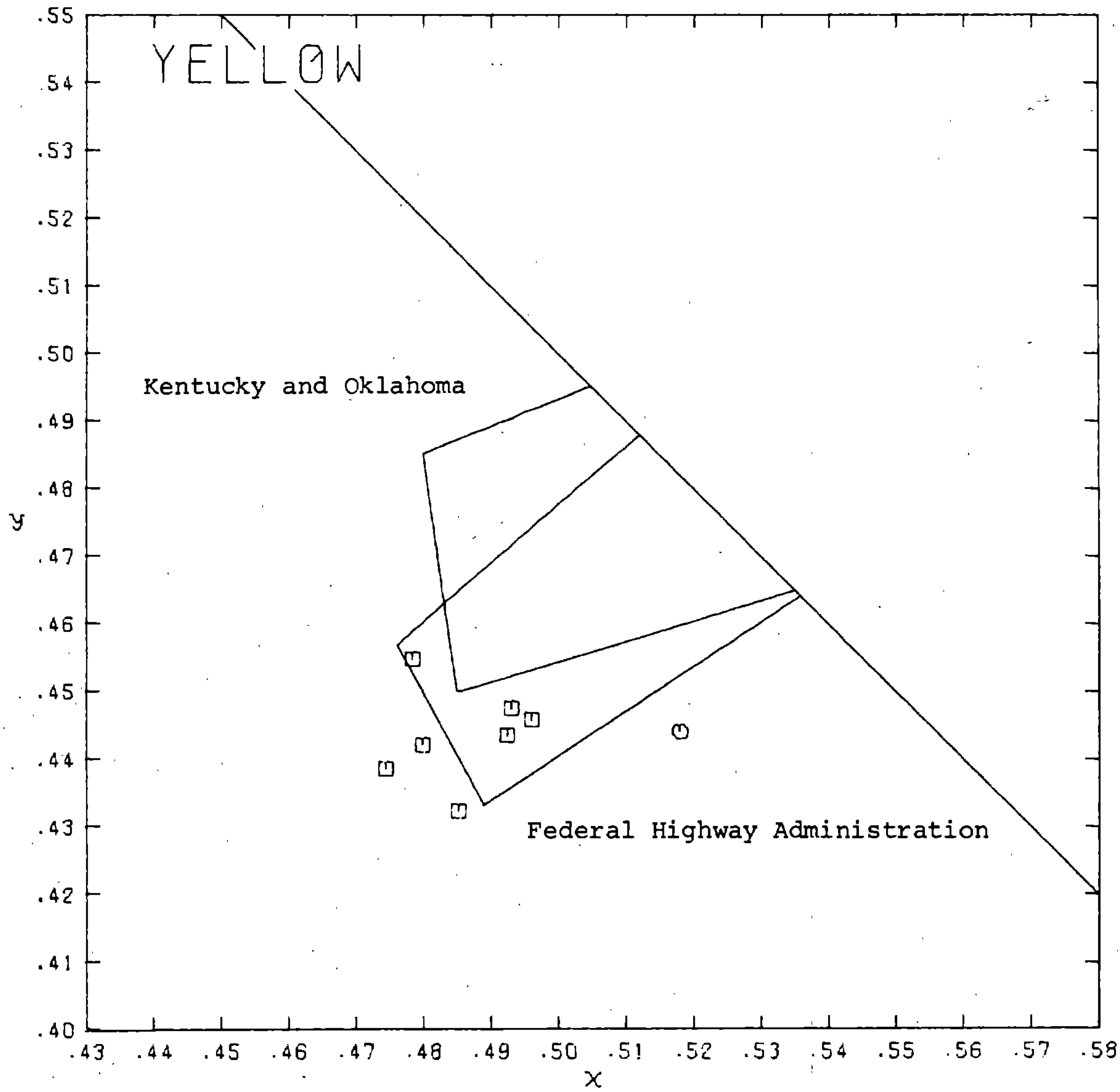

Figure 2. Chromaticity coordinates of various tolerance regions and the standards used in the:
□, visual measurements,
○, photoelectric measurements.
The chromaticity coordinates of the standards were spectrophotometrically derived.

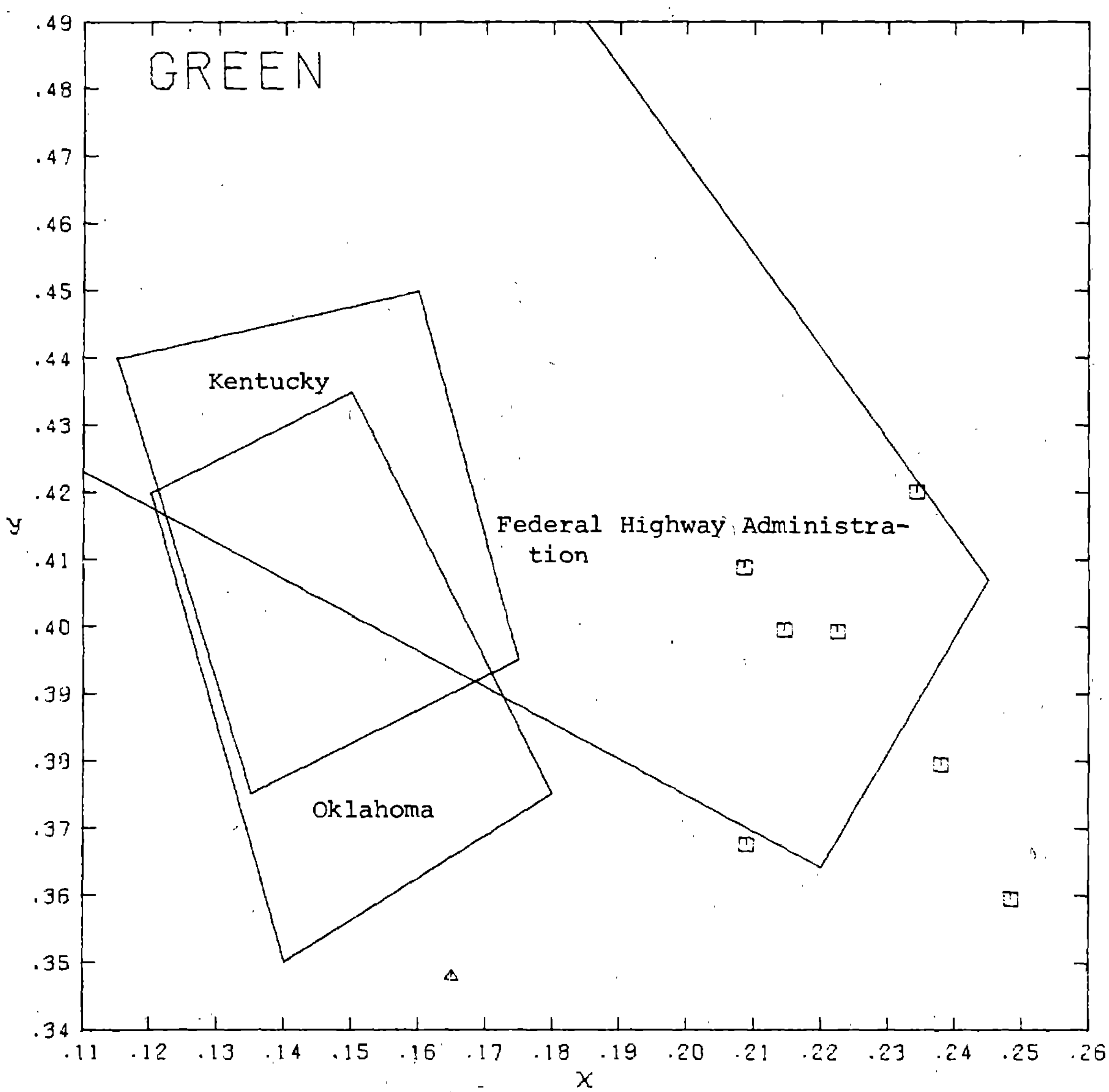

Figure 3. Chromaticity coordinates of various tolerance regions and the standards used in the:
□ , visual measurements,
△ , photoelectric measurements.
The chromaticity coordinates of the standards were spectrophotometrically derived.

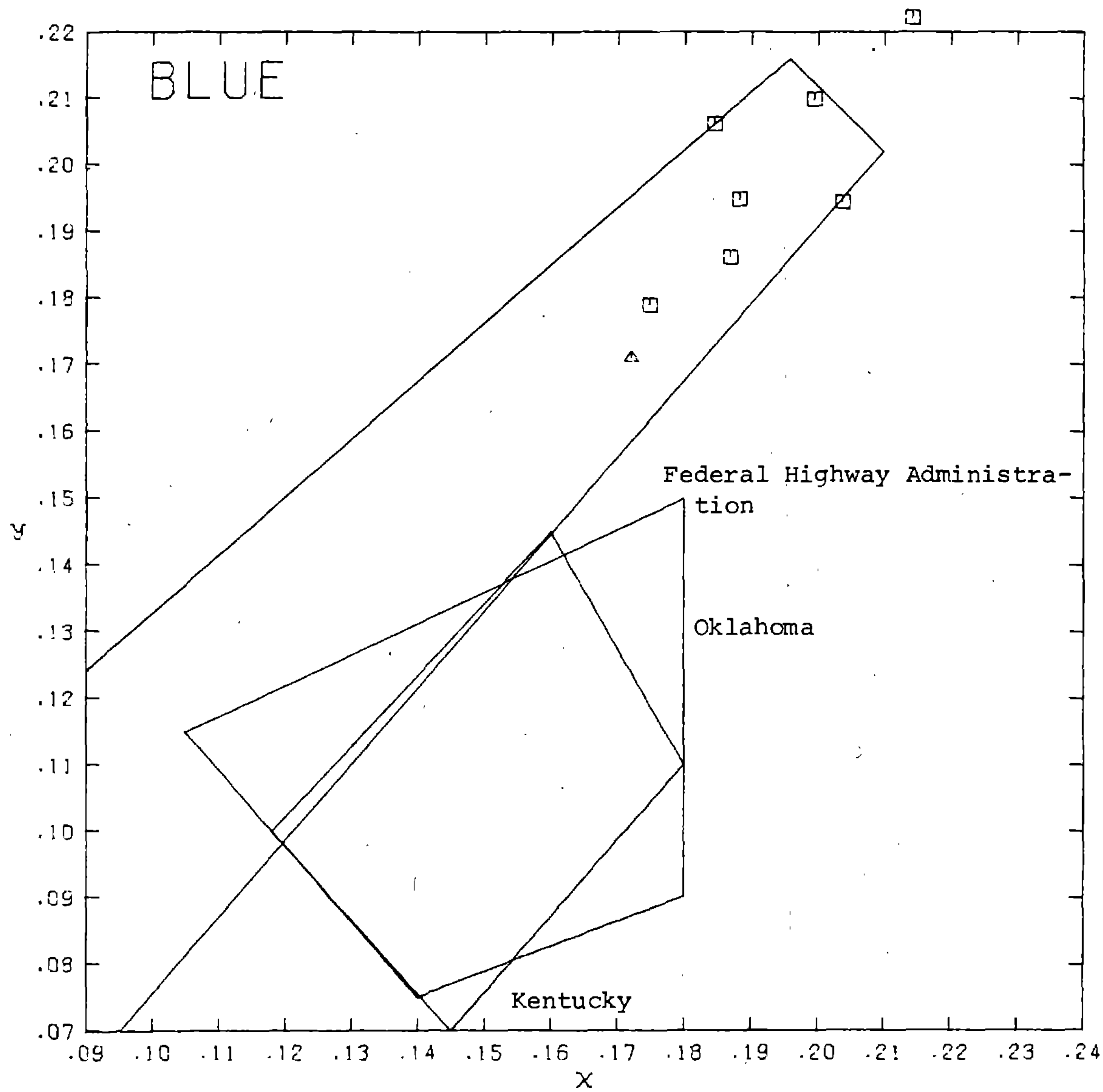

Figure 4. Chromaticity coordinates of the various tolerance regions and the standards used in the:
□ , visual measurements,
△ , photoelectric measurements.
The chromaticity coordinates of the standards were spectrophotometrically derived.

The standards used for visual evaluations were the seven unreflectorized color chips depicted in each of the Highway Color Tolerance Charts, for red, yellow, green, and blue colors supplied by the Department of Transportation. The spectrophotometrically derived chromaticity coordinates of these standards are shown as squares in Figures 1, 2, 3, and 4. It is evident from these figures that, since the time of their manufacture, these chips have faded from the values published on the charts. Because of this fading, it is suggested that the color of the chips on the Highway Color Tolerance Charts be checked periodically to verify the color validity of these standards and determine if they need to be replaced by new chips. Reasonably, such verification of these standard color chips may be made at five year intervals.

The boundary areas shown in these four figures were obtained from graphs supplied by the Department of Transportation as examples of highway sign color specifications. The boundaries shown for the Federal Highway Administration are those of the National Joint Committee on Uniform Traffic Control Devices and are represented on the Highway Color Tolerance Charts by chips whose color designations were derived from instrumental measurements of unreflectorized materials. On the other hand, the boundaries designated as Oklahoma and Kentucky are regions selected by the respective State highway departments for reflectorized sheeting materials.

The boundaries and the equations for lines that define the tolerance limits of the red, yellow, green, and blue highway sign colors are shown on the complete CIE chromaticity diagram of Figure 5. Also shown by shaded areas on the diagram are the possible red and green colors that could be confused by protanopic observers when these colors have equal luminous reflectance. The lines that bound these shaded areas meet at the protanopic convergence point, P. Since specifications for the green and the red colors limit their luminous reflectance between 3.82 and 10.43 percent and between 6.56 and 12.00%, respectively, there is a strong likelihood that these colors would be confused. To minimize this problem it is suggested that the specified tolerance area for the red colors be shifted slightly toward orange.

The standards used on the colorimeters for the red and yellow samples were porcelain-enameled standards of chromaticity coordinates sufficiently close to their respective chromaticity tolerance regions of the sample colors. These chromaticity coordinates are shown in Figures 1 and 2 as an octagon. The standards used on the colorimeters for the green and blue samples were glossy Munsell chips of chromaticity coordinates sufficiently close to their respective chromaticity tolerance regions of the sample colors. These

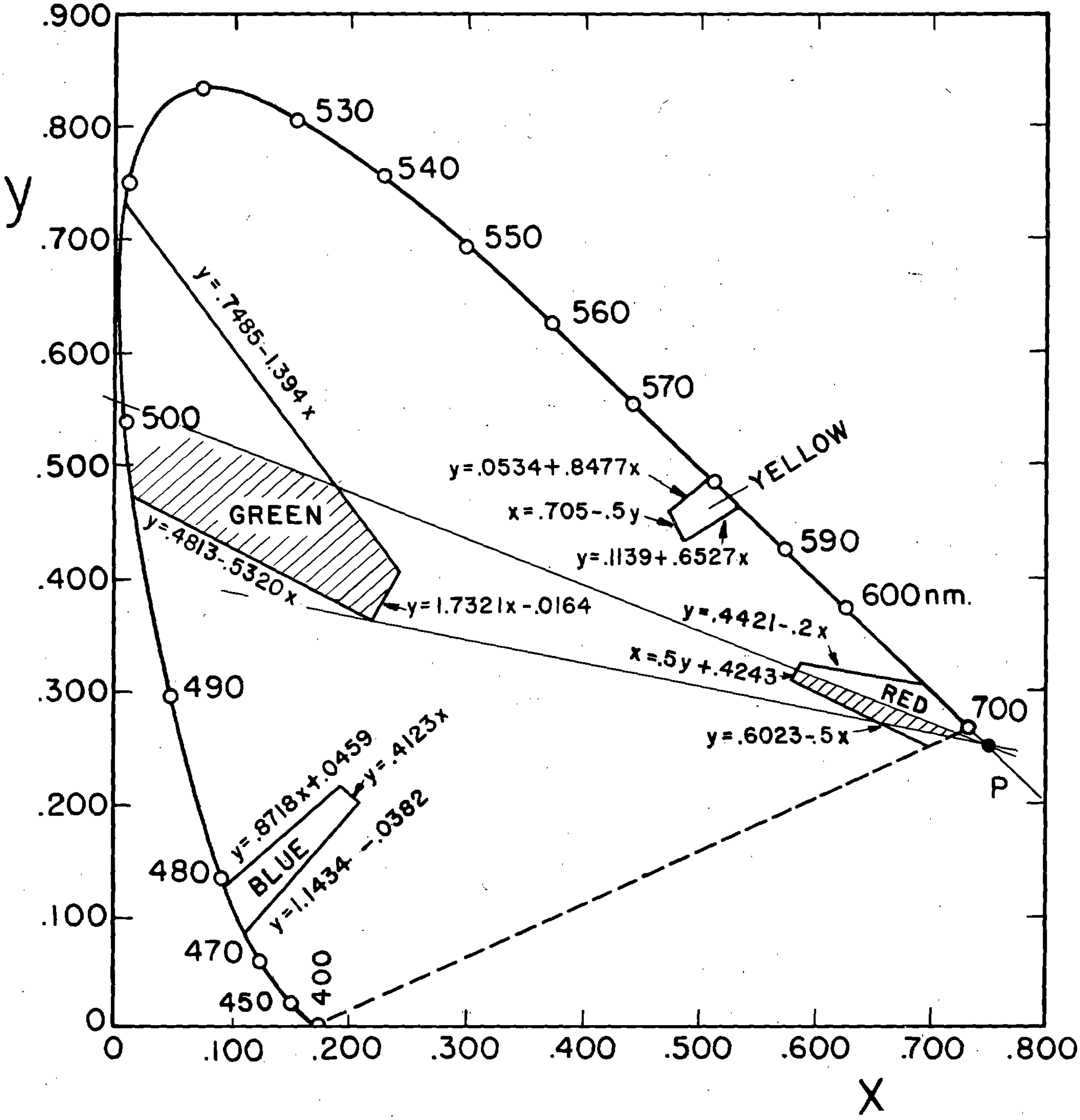

Figure 5. The 1931 CIE chromaticity diagram showing NJCUTCD boundaries for surface colors. Shaded areas indicate possible red-green confusion colors for the protanopic convergence point, P, that lie within the red and green boundaries.

chromaticity maticity coordinates are shown in Figures 3 and 4 as a triangle.

III. RESULTS OF THE STUDY

The chromaticity coordinates results of the study on seventy-four reflectorized sheeting samples are shown in Figures 6, 7, 8, and 9 together with the color tolerance regions for the red, yellow, green, and blue samples, respectively. The chromaticity-coordinate data are also listed in Tables I, II, III, and IV for the red, yellow, green, and blue samples, respectively, as obtained by means of visual estimates and by means of spectrophotometer and photoelectric tristimulus colorimeter measurements. The visual data are the median values of the observations made by the five observers.

The tabulated data shows a general consistency among the values obtained with the instruments that have diffuse illumination and undirectional view (the spectrophotometers and the Color Eye Colorimeter) and the data obtained visually. The data obtained on the colorimeters that have 45°,0° geometry (Colormaster colorimeter and Hunter Color and Color Difference Meter) also were generally consistent among themselves. To show this general consistency we computed the average values of the chromaticity coordinates of those

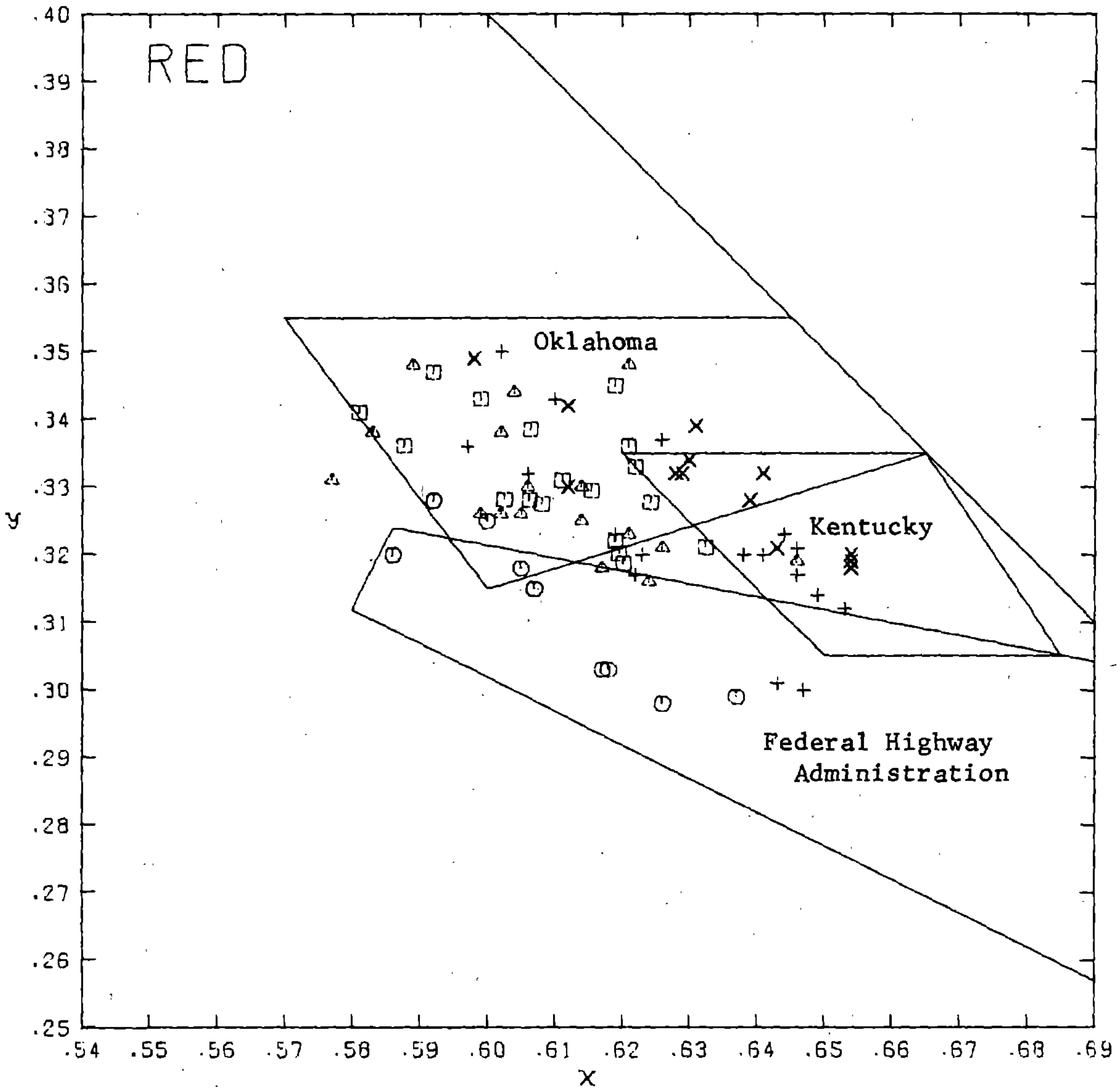

Figure 6. Chromaticity coordinates of the tolerance regions and of the samples obtained by several procedures:
- ⊙, visual,
- ⊡, spectrophotometers,
- △, color eye colorimeter,
- +, colormaster colorimeter,
- ×, Hunter color and color difference meter.

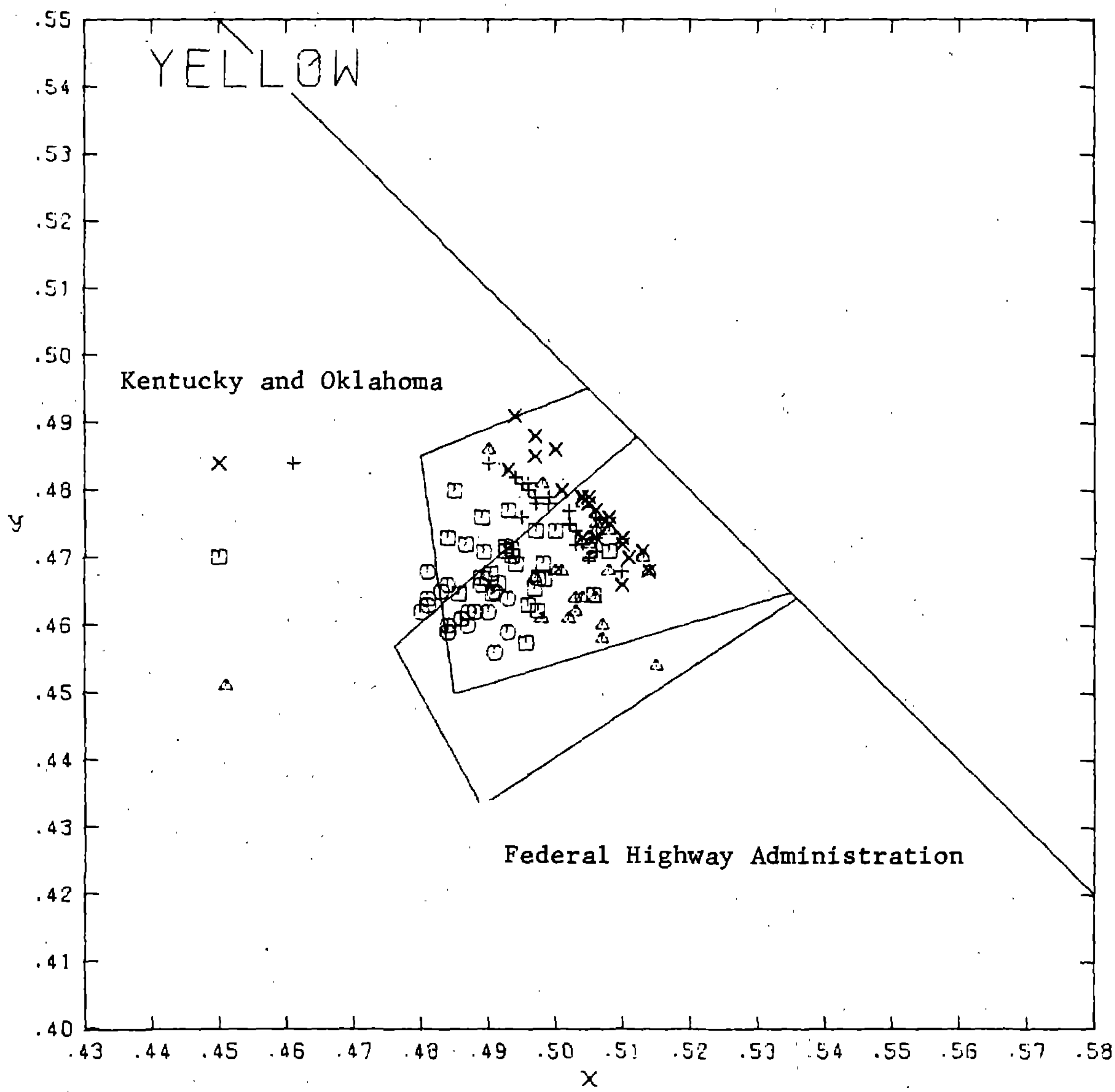

Figure 7. Chromaticity coordinates of the tolerance regions and of the samples obtained by several procedures:
- ⊙, visual,
- ⊡, spectrophotometer,
- △, color eye colorimeter,
- +, colormaster colorimeter,
- ×, Hunter color and color difference meter.

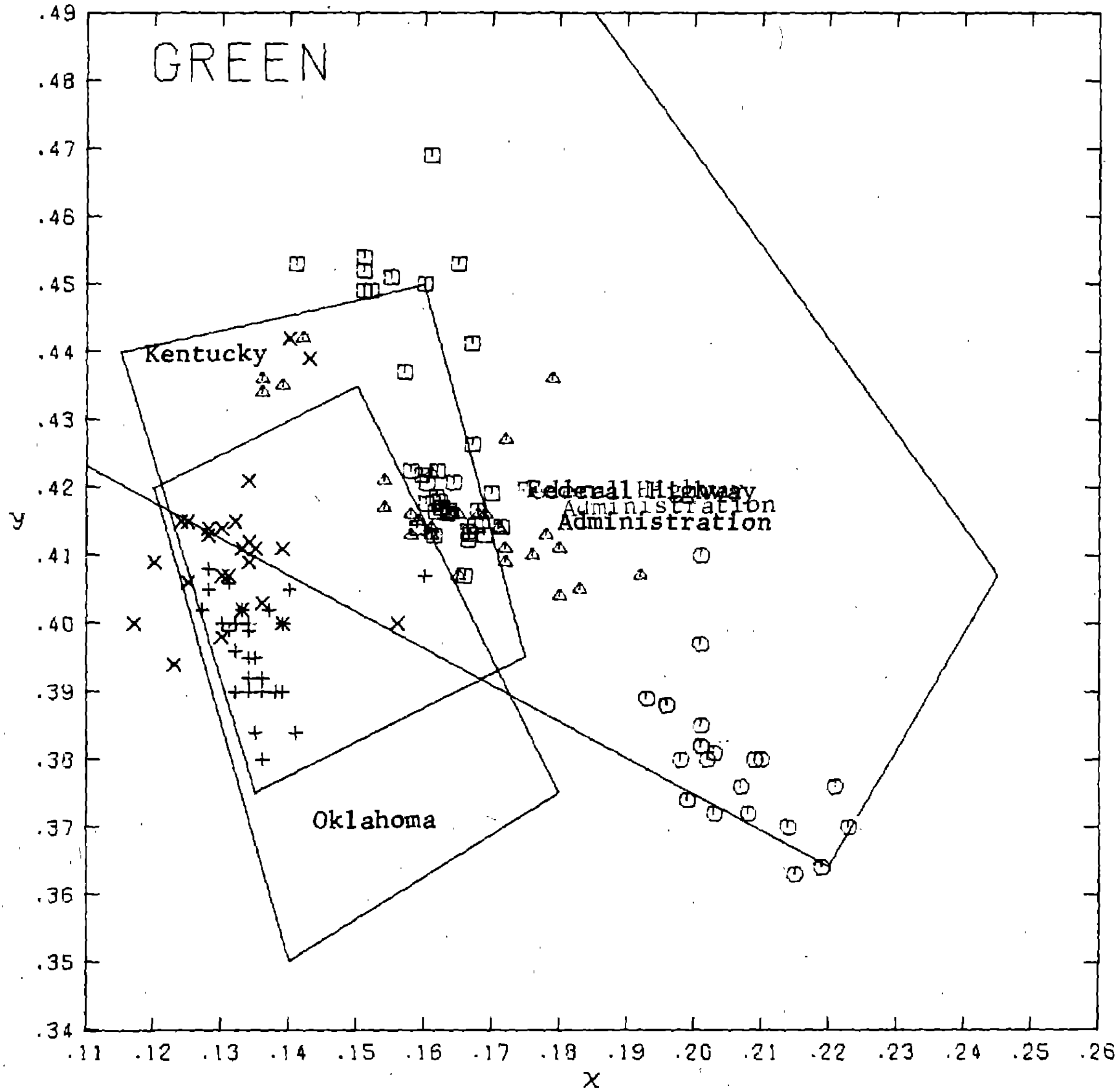

Figure 8. Chromaticity coordinates of the tolerance regions and of the samples obtained by several procedures:

⊙, visual

⊡, spectrophotometer,

△, color eye colorimeter,

+, colormaster colorimeter,

×, Hunter color and color difference meter.

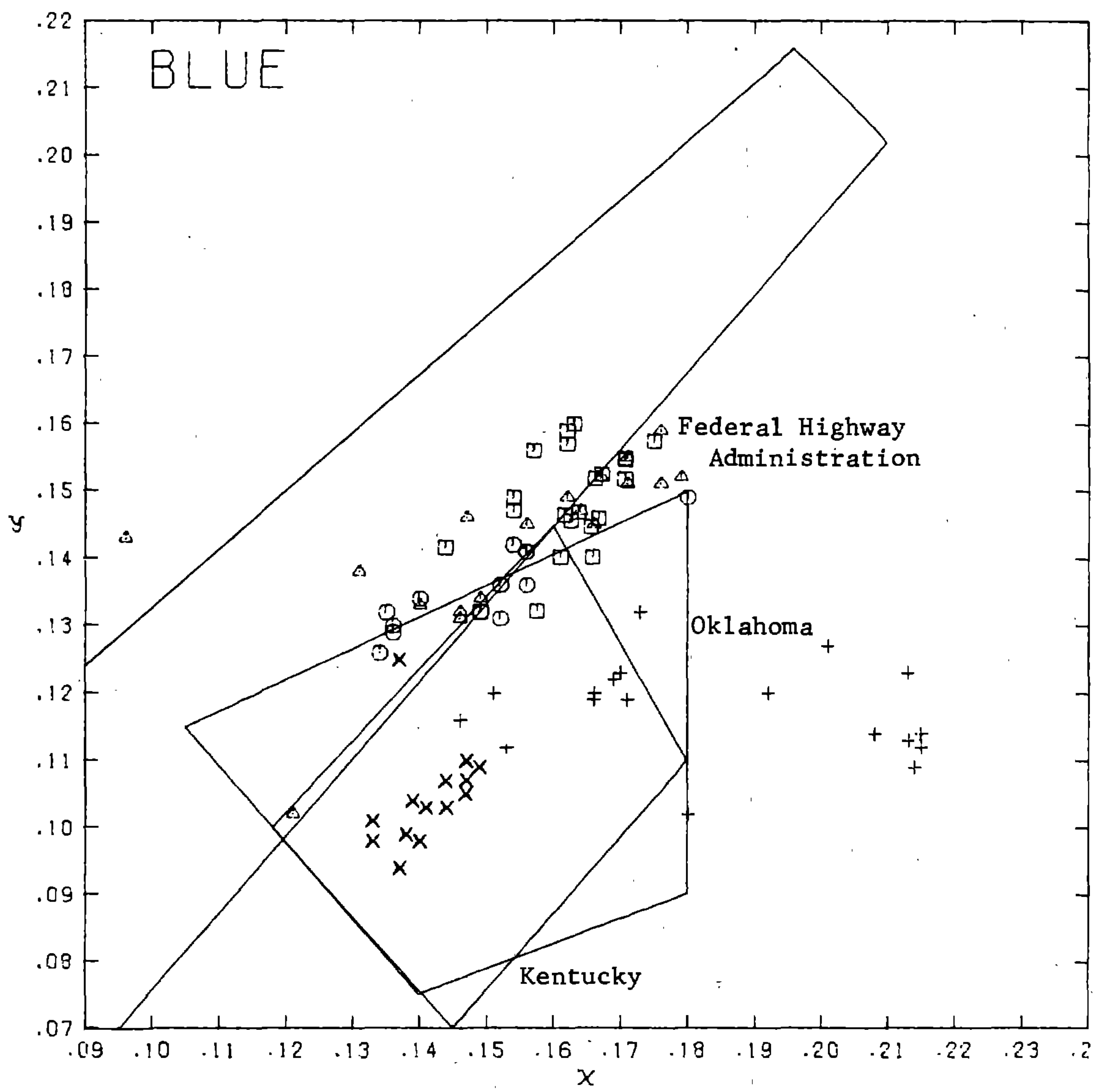

Figure 9. Chromaticity coordinates of the tolerance regions and of the samples obtained by several procedures:

- ⦶, visual
- ⊡, spectrophotometer,
- △, color eye colorimeter,
- +, colormaster colorimeter
- x, Hunter color and color difference meter.

TABLE I. CHROMATICITY COORDINATES FOR RED SPECIMENS

SPECIMEN	VISUAL		SPECTROPHOTOMETER CARY		SPECTROPHOTOMETER KCS 40		COLOR EYE NBS		COLOR EYE 3M		COLORMASTER NBS		COLORMASTER 3M		HUNTER COLOR AND COLOR DIFF. METER	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
12-18-70	0.626	0.298	0.632	0.321	--	--	0.626	0.321	--	--	0.643	0.301	--	--	0.654	0.320
11-13-70	.617	.303	--	--	--	--	.621	.323	--	--	.653	.312	--	--	.643	.321
11- 5-70	.586	.320	.606	.328	0.619	0.322	.599	.326	--	--	.646	.321	--	--	.612	.330
11- 3-70	.607	.315	.615	.330	--	--	.606	.330	--	--	.638	.320	--	--	.630	.334
9- 1-70	.586	.320	.602	.328	--	--	.605	.326	--	--	.641	.320	--	--	.629	.332
8-31-70	.607	.315	.608	.328	.622	.333	.602	.326	--	--	.646	.317	--	--	.628	.332
7-21-70	.618	.303	.619	.320	--	--	.617	.318	--	--	.647	.300	--	--	.654	.318
72-1B	.592	.328	.588	.336	.599	.343	.583	.338	0.604	0.344	.610	.343	0.606	0.332	.612	.342
72-2B	.600	.325	.606	.339	.619	.345	.602	.338	.621	.348	.623	.320	.626	.337	.631	.339
72-3B	.592	.328	.581	.341	.592	.347	.577	.331	.589	.348	.602	.350	.597	.336	.598	.349
282	.605	.318	.611	.331	.621	.336	.614	.330	--	--	.619	.323	--	--	.641	.332
21086	--	--	.624	.328	--	--	.614	.325	--	--	.622	.317	--	--	.639	.328
ALASKA 63	.637	.299	.620	.319	.645	.321	.624	.316	.646	.319	.649	.314	.644	.323	.654	.319

TABLE II. CHROMATICITY COORDINATES FOR YELLOW SPECIMENS

SPECIMEN	VISUAL		SPECTROPHOTOMETER CARY		SPECTROPHOTOMETER KCS 40		COLOR EYE NBS		COLOR EYE 3M		COLORMASTER NBS		COLORMASTER 3M		HUNTER COLOR AND COLOR DIFF. METER	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
5-14-70	0.483	0.465	0.493	0.472	--	--	0.503	0.464	--	--	0.496	0.481	--	--	0.505	0.478
4-13-70 (174)	.480	.462	.487	.472	--	--	.501	.468	--	--	.494	.482	--	--	.501	.480
4-13-70 (8)	.481	.463	.492	.466	--	--	.506	.464	--	--	.502	.475	--	--	.508	.475
2-20-70 (104)	.487	.460	.499	.467	0.500	0.474	.503	.462	--	--	.506	.471	--	--	.511	.470
2-20-70 (92)	.491	.456	.506	.465	.508	.471	.515	.454	--	--	.510	.468	--	--	.514	.468
1- 6-70	.481	.464	.498	.469	--	--	.502	.461	--	--	.504	.472	--	--	.506	.473
71-1C	.491	.465	.498	.467	.497	.474	.507	.460	0.504	0.478	.506	.473	0.506	0.476	.500	.486
71-2B	.486	.461	.489	.467	.489	.476	.504	.464	.498	.481	.502	.477	.499	.479	.497	.488
71-3B	.489	.466	.484	.473	.485	.480	.497	.467	.490	.486	.496	.480	.490	.484	.497	.485
281	.486	.461	.493	.471	.493	.477	.498	.461	--	--	.497	.478	--	--	.493	.483
81	--	--	.450	.470	--	--	.451	.451	--	--	.461	.484	--	--	.450	.484
ALASKA 63	.493	.464	.496	.457	.496	.463	.507	.458	.500	.468	.506	.471	.505	.470	.510	.466
5- 8-68	.493	.459	.490	.468	--	--	.513	.470	--	--	.502	.475	--	--	.510	.473
11- -68	.488	.462	.497	.462	--	--	.514	.468	--	--	.503	.474	--	--	.510	.472
12- -68	.487	.462	.486	.465	--	--	.505	.470	--	--	.495	.476	--	--	.504	.473
2- 4-69	.484	.466	.489	.471	--	--	.506	.475	--	--	.494	.482	--	--	.504	.479
5- -69	.481	.468	.494	.471	--	--	.506	.474	--	--	.495	.481	--	--	.505	.479
5-22-69	.484	.460	.494	.469	--	--	.508	.468	--	--	.499	.478	--	--	.494	.491
9-18-69	.490	.462	.497	.465	--	--	.507	.475	--	--	.502	.475	--	--	.513	.471
10- 7-69	.484	.459	.491	.465	--	--	.505	.472	--	--	.503	.472	--	--	.506	.477
11-10-69	.484	.459	.494	.470	--	--	.508	.474	--	--	.497	.479	--	--	.508	.476

TABLE III. CHROMATICITY COORDINATES FOR GREEN SPECIMENS

SPECIMEN	VISUAL		SPECTROPHOTOMETER CARY		SPECTROPHOTOMETER KCS 40		COLOR EYE NBS		COLOR EYE 3M		COLORMASTER NBS		COLORMASTER 3M		HUNTER COLOR AND COLOR DIFF. METER	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
6-10-70	0.196	0.388	0.161	0.413	--	--	0.161	0.413	--	--	0.136	0.390	--	--	0.134	0.409
6- 5-70	.201	.397	.167	.412	--	--	.158	.413	--	--	.134	.390	--	--	.133	.402
3- 2-70 20''	.196	.388	.162	.417	--	--	.172	.409	--	--	.141	.384	--	--	.139	.400
3- 2-70 30''	.202	.380	.166	.413	--	--	.154	.417	--	--	.134	.395	--	--	.134	.412
3- 2-70 36''	.193	.389	.162	.416	--	--	.159	.415	--	--	.132	.396	--	--	.133	.411
3- 2-70 44''	.193	.389	.162	.422	--	--	.154	.421	--	--	.131	.406	--	--	.136	.403
220-1 NR	.215	.363	.166	.407	0.157	0.437	.165	.407	--	--	.128	.405	--	--	.130	.414
3277-1	.203	.372	.160	.422	.151	.452	.165	.416	--	--	.130	.400	--	--	.125	.415
3277-2	.199	.374	.158	.422	.141	.453	.161	.422	--	--	.132	.400	--	--	.124	.415
3277-3	,199	.374	.160	.418	.151	.449	.163	.417	--	--	.132	.390	--	--	.125	.406
77-1A	.219	.364	.159	.414	.152	.449	.161	.414	0.136	0.434	.132	.390	0.134	0.399	.117	.400
77-2A	.201	.382	.160	.421	.151	.454	.164	.416	.136	.436	.134	.392	.134	.400	.120	.409
77-3A	.201	.410	.163	.416	.155	.451	.172	.411	.139	.435	.135	.384	.136	.392	.123	.394
287	.223	.370	.167	.441	.161	.469	.179	.436	--	--	.128	.408	--	--	.143	.439
87	--	--	.167	.426	--	--	.172	.427	--	--	.127	.402	--	--	.140	.442
ALASKA 63	.207	.376	.170	.419	.165	.453	.158	.416	.142	.442	.137	.402	.140	.405	.134	.421
10- 7-68	.221	.376	.171	.414	--	--	.171	.414	--	--	.132	.400	--	--	.132	.415
10- 8-68	.198	.380	.167	.413	--	--	.180	.404	--	--	.133	.402	--	--	.135	.411
11- -68	.214	.370	.162	.419	--	--	.176	.410	--	--	.131	.399	--	--	.128	.414
12- -68	.210	.380	.168	.417	--	--	.169	.416	--	--	.139	.400	--	--	.139	.411
1- 2-69	.203	.381	.164	.417	--	--	.168	.416	--	--	.160	.407	--	--	.156	.400
2- 4-69	.209	.380	.169	.413	--	--	.178	.413	--	--	.135	.395	--	--	.128	.413
5- 2-69	.208	.372	.162	.418	--	--	.180	.411	--	--	.138	.390	--	--	.131	.407
10- 7-69	.201	.382	.164	.421	--	--	.183	.405	--	--	.136	.380	--	--	.130	.398
11-10-69	.201	.385	.168	.414	--	--	.192	.407	--	--	.139	.390	--	--	.130	.407

TABLE IV. CHROMATICITY COORDINATES FOR BLUE SPECIMENS

SPECIMEN	VISUAL X	VISUAL Y	SPECTROPHOTOMETER CARY X	CARY Y	KCS 40 X	KCS 40 Y	COLOR EYE NBS X	NBS Y	3M X	3M Y	COLORMASTER NBS X	NBS Y	3M X	3M Y	HUNTER COLOR AND COLOR DIFF. METER X	Y
6-10-70 1B	0.156	0.141	0.171	0.155	0.162	0.159	0.171	0.155	--	--	0.215	0.112	--	--	0.147	0.107
6-10-70 2B	.154	.142	.171	.155	.163	.160	.176	.159	--	--	.213	.113	--	--	.147	.110
6- 5-70	.156	.141	.171	.152	.162	.157	.176	.151	--	--	.214	.109	--	--	.144	.103
4-13-70	.152	.136	.161	.140	--	--	.131	.138	--	--	.215	.114	--	--	.140	.098
3- 2-70	.156	.136	.164	.147	--	--	.164	.147	--	--	.208	.114	--	--	.149	.109
10-13-70	.149	.132	.157	.132	.149	.132	.121	.102	--	--	.180	.102	--	--	.147	.110
75-1A	.180	.149	.166	.145	.154	.149	.166	.145	0.146	0.131	.213	.123	0.153	0.112	.137	.094
75-2A	.152	.131	.166	.152	.157	.156	.156	.145	.149	.134	.201	.127	.151	.120	.133	.098
75-3A	.152	.136	.162	.146	.154	.147	.140	.133	.146	.132	.192	.120	.146	.116	.133	.101
85	--	--	.144	.142	--	--	.096	.143	--	--	.166	.119	--	--	.137	.125
5- 8-68	.140	.134	.167	.152	--	--	.167	.152	--	--	.171	.119	--	--	.139	.104
2- 4-69	.136	.129	.167	.146	--	--	.171	.151	--	--	.173	.132	--	--	.147	.105
5- 2-69	.136	.130	.166	.140	--	--	.147	.146	--	--	.169	.122	--	--	.138	.099
5-22-69	.134	.126	.175	.157	--	--	.162	.149	--	--	.166	.120	--	--	.141	.103
10- 7-69	.135	.132	.162	.146	--	--	.179	.152	--	--	.170	.123	--	--	.144	.107

specimens that were measured at the National Bureau of Standards by the several procedures. These averages, together with the chromaticity coordinates of the central specification colors of the tolerance charts, are shown on Figures 10, 11, 12, and 13 for the red, yellow, green, and blue samples, respectively. These figures show that the average chromaticity-coordinate points that represent the data obtained on the instruments with diffuse illumination and unidirectional viewing are closer to the chromaticity coordinate points of the respective central color of the color tolerance charts as well as to the visually derived data. This concordance tends to confirm the concept that with materials that exhibit geometrically selective reflectance characteristics, as retroreflective sheeting materials do, the measurement geometry should approximate the use geometry as closely as feasible.

It should be noted that in the present study the visual evaluations were made only of small samples at close range. Whether these results correlate with observations of larger, sign-size areas under various conditions of highway sign placement as seen from an automobile, is presently unknown. Study of this aspect of the problem should be undertaken if approximation to use conditions is to be the basis for adopting a new procedure.

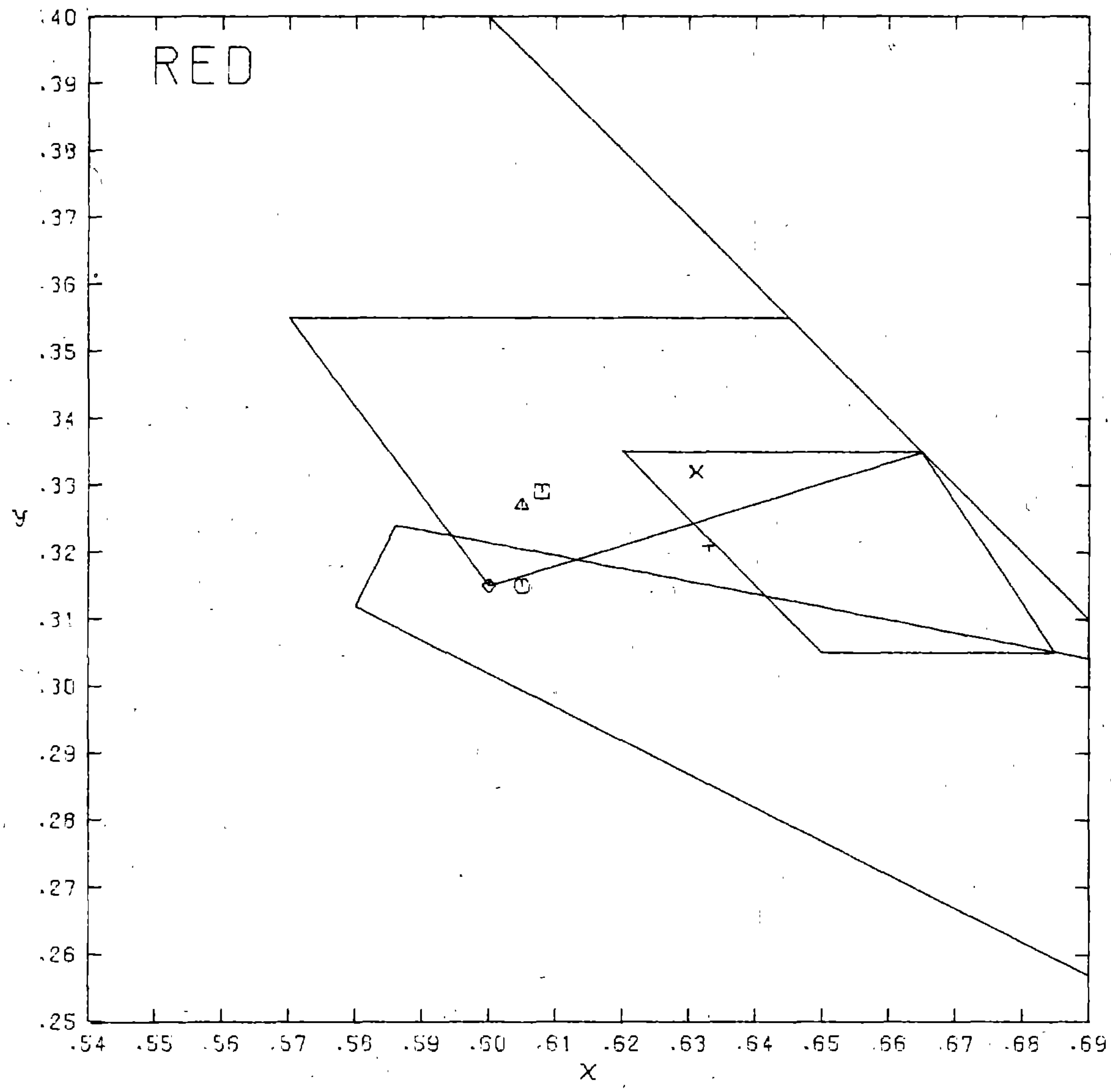

Figure 10. Average chromaticity coordinates by procedures:
◇ , FHWA specification,
○ , visual,
□ , spectrophotometer,
△ , color eye colorimeter,
+ , colormaster colorimeter,
x , Hunter color and color difference meter.

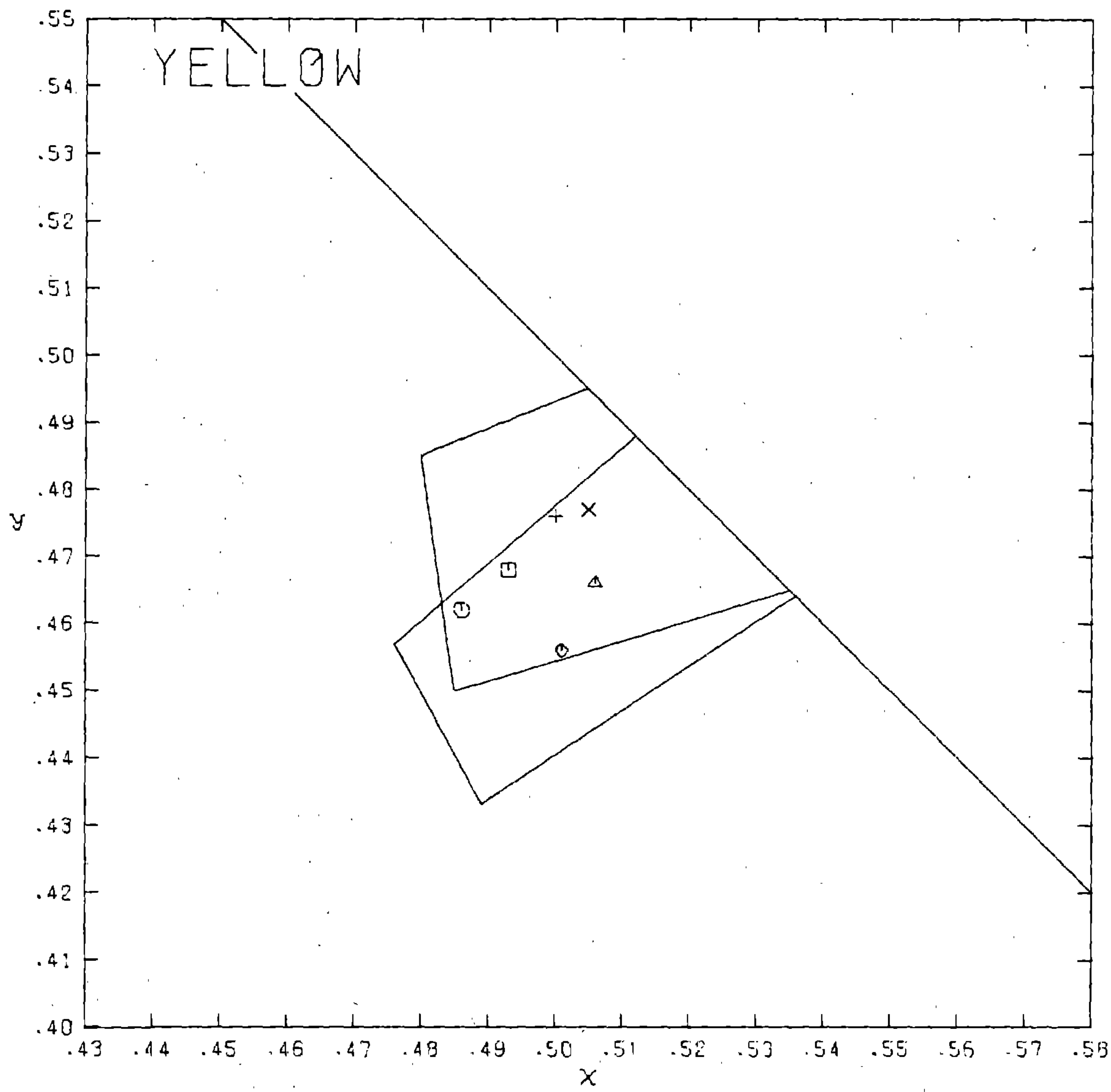

Figure 11. Average chromaticity coordinated by procedures:
◇ , FHWA specification,
○ , visual,
□ , spectrophotometer,
△ , color eye colorimeter,
+ , colormaster colorimeter,
× , Hunter color and color difference meter.

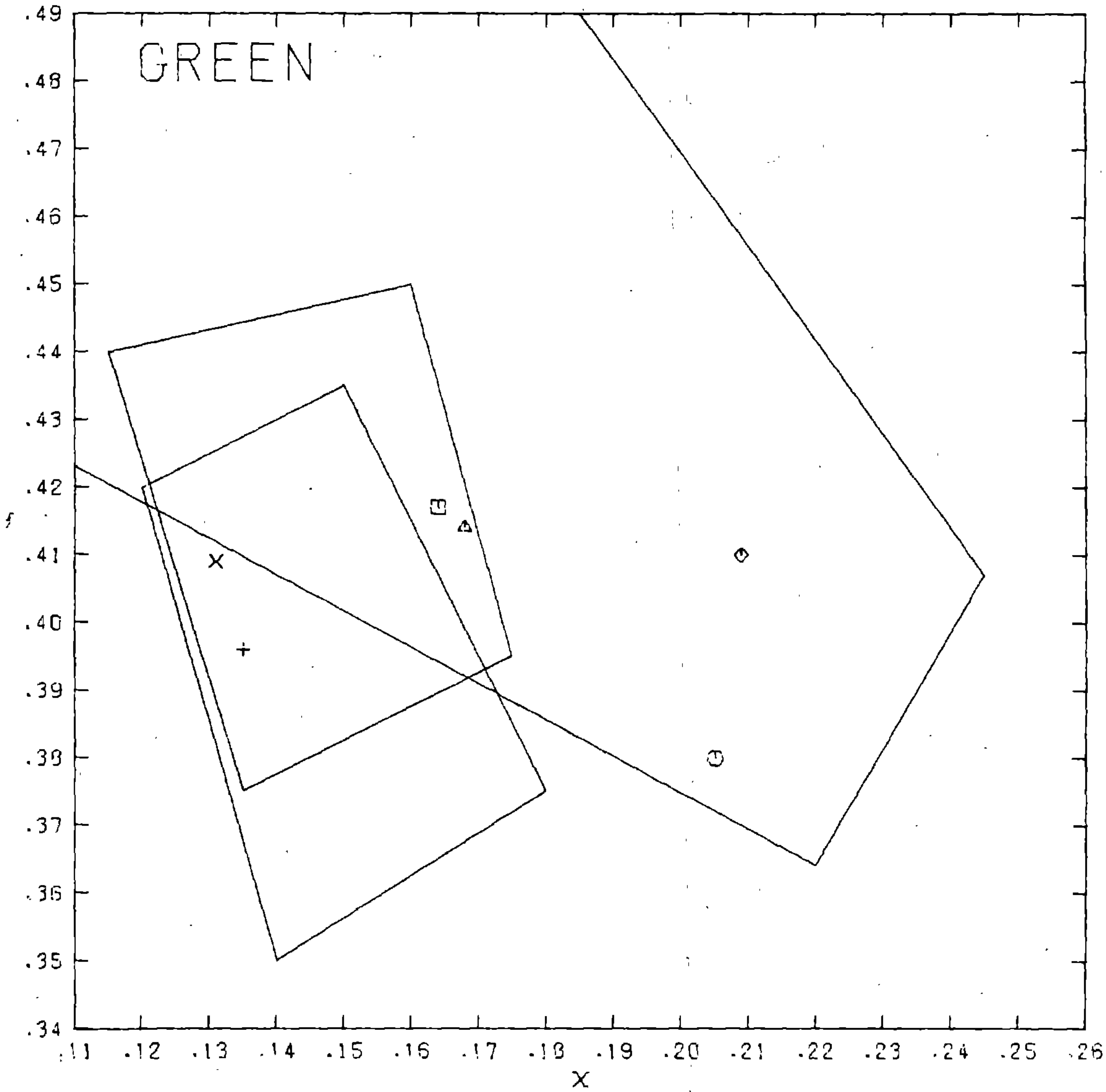

Figure 12. Average chromaticity coordinates by procedures:
◇, FHWA specification,
○, visual,
□, spectrophotometer,
△, color eye colorimeter,
+, colormaster colorimeter,
X, Hunter color and color difference meter.

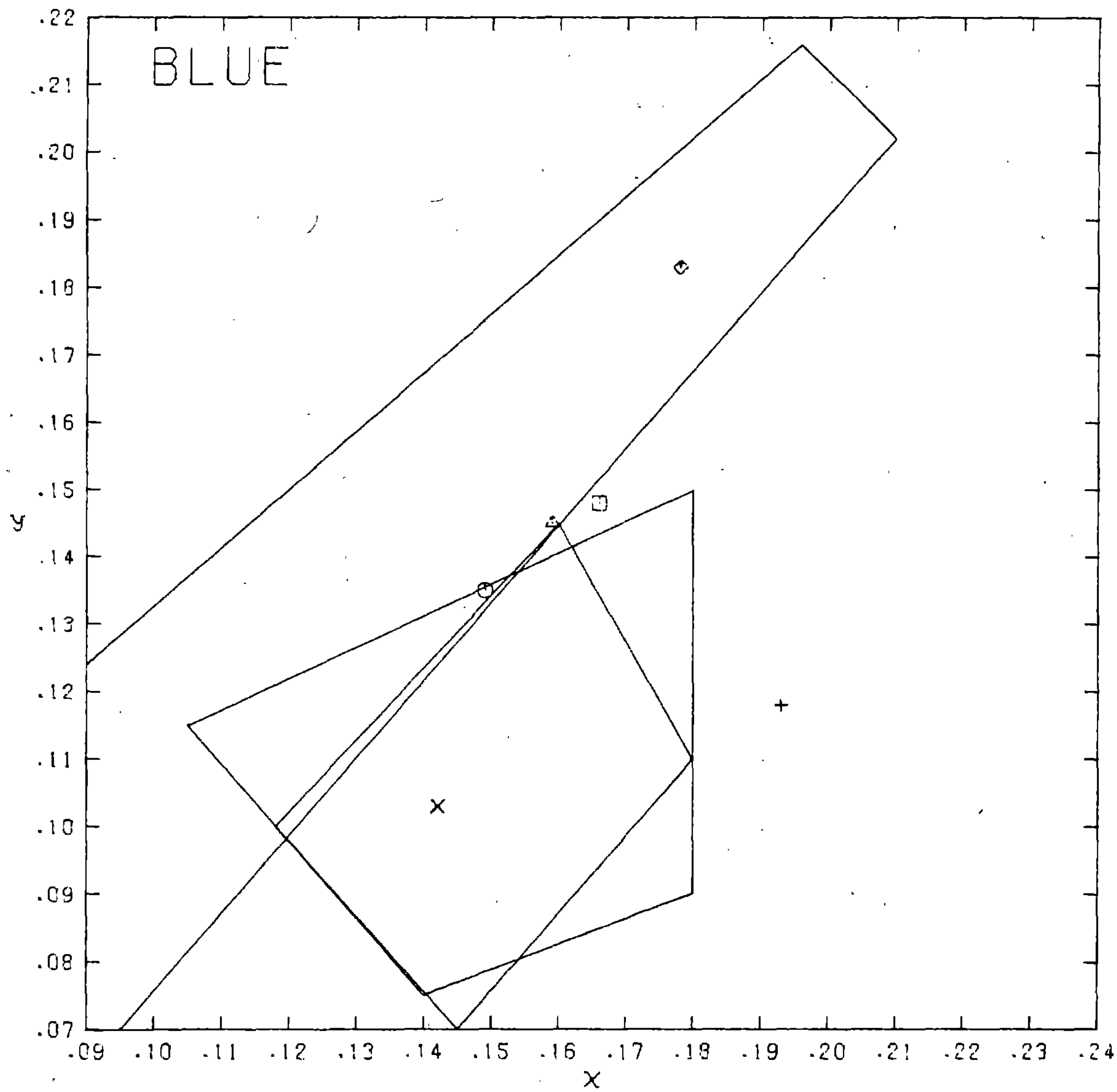

Figure 13. Average chromaticity coordinates by procedures:
◇ , FHWA specifications,
○ , visual,
□ , spectrophotometer,
△ , color eye colorimeter,
+ , colormaster colorimeter,
× , Hunter color and color difference meter.

IV. CONCLUSIONS AND IMPLEMENTATION

The results of the measurement of the color of the retroreflective highway sign materials indicate that there is a tendency for the instruments that have diffuse illumination and unidirectional viewing geometry to produce chromaticity data that agree better with chromaticity data obtained by visual observation in actual daylight conditons than data produced by colorimeters with 45°,0° geometry. In general, under diffuse illumination conditions the specimen colors appear less saturated (weaker chroma) than under unidirectional illumination at 45° from the perpendicular to the specimens.

These results would appear to suggest the need for changing the specifications for color measurement from the present 45°,0° condition, as in the Oklahoma and Kentucky specifications to diffuse illumination and unidirectional view. The measured chromaticity coordinates of the samples under 45°,0° geometry do tend to meet the specification by any of the existing specifications for color measurement of reflectorized sheeting materials from the Oklahoma and the Kentucky State road commissions.

An immediate change in the specification of the color measurement conditons could work a hardship on the present users of the 45°,0° photoelectric colorimeters. They may have a considerable amount of funds committed to their present instrumentation.

There appear to be two choices by which to implement the results of this study that might minimize the effects of changing to new instrumentation. First, we may prepare a specification that has a preferred procedure and an alternate procedure. The preferred procedure would specify the color tolerances for diffuse illumination and unidirectional viewing. The alternate procedure would specify the color tolerances under 45°,0° conditions. Thus, we would permit use of instrumentation with either geometry. Tolerance areas for each of these conditions could differ somewhat, but could have overlapping areas.

Secondly, we might develop an interim specification that has the two procedures outlined above but also contains a statement that the alternate procedure is to be deprecated after a sufficient lapse of time, say five years, during which long-range, large-area color evaluation can be studied. This latter choice would permit those laboratories that have an investment in colorimeters with 45°,0° geometry to gradually replace their present colorimeters with instrumentation more suitable to this second specificaton procedure after it is adopted.

V. COLORIMETRY UNDER SIMULATED NIGHTTIME CONDITIONS

Materials that exhibit geometrically selective reflectance characteristics, as do the retroreflective materials for highway signs, require that the actual use conditions be simulated as closely as convenient by the measuring conditions. Such is the situation regarding the color measurment of retroreflective materials for daytime and nighttime use.

In suggesting further work on the color measurement of reflective materials for highway signs, particularly for nighttime driving conditions, some consideration was given to finding or devising suggestions for a possible solution to this problem. The problem of simulating the geometry of nighttime conditions for color measurement involves approximating of illumination of the materials unidirectionally by the automobile headlights and viewing of the retroreflective light flux unidirectionally at small divergence angles from the direction of illumination.

Instrumental color measurement requires that the reflected beam be attenuated by optical filters that simulate, together with the spectral response of the photodetector, the average normal human eye response to colored light. It is, however, required that sufficient light reach the photoreceptor to give adequate response for correct color evaluation. To provide sufficient space to accomodate the source and receiver at small angular divergence, these components must be placed a some distance from the reflective material. This placement of the components at a distance from the test material further reduces the amount of light that reaches the receptor.

One instrument that is available is the ESNA reflex-photometer that directly measures the amount of light reflected at specified divergence angles by retroreflective materials. By the insertion of optical filters that comply with the 1931 CIE standard observer system into the reflected beam it may be possible to convert this photometer into a photoelectric colorimeter.

Another possible method by which to avoid placing the photoreceptor at too great a distance from the test material involves the use of a beam splitter in the path of incident and reflected beams. The photoreceptor and optical filters can then be moved across the beam reflected first by the test material and then by the splitter of the proper position of the divergence angle at which the color is to be measured. This procedure, however, requires correct alignment of the beam-splitter in the light beam.

There is yet another procedure which might avoid or at least minimize the alignment difficulties and still accommodate small divergence angles. This procedure involves the use of fiber optics, commonly called "flexible light pipes." These pipes are of small diameter so that they can be placed close to the test material and collect the light reflected at small divergence angles.

Research, or study, with these several alternatives would be required to determine which would yield optimun concordance with visual judgements of color under nighttime conditions.

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