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**Federal Transit
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Detectable Warning Surfaces: Color, Contrast, and Reflectance

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The visual contrast of ten detectable warning surface/platform pairs was measured on an interior platform illuminated at 20 foot-candles, as recommended by the Americans with Disabilities Act Accessibility Guidelines (ADAAG) A4.29.2, by 24 persons having very low vision.

Tests included objective and subjective measures of visual detectability. Objective measures were accuracy (correct identification of the presence of a warning surface) and response time. Subjective measures were each participant's choice of the three most visually detectable contrasts, the one most visually detectable contrast, and the least visually detectable contrast.

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PREFACE

This document presents the results of objective and subjective measures of visual detectability. The visual contrast of ten detectable warning surface/platform pairs was measured on an interior platform illuminated at 20 foot candles, as recommended by the Americans with Disabilities Act Accessibility Guidelines (ADAAG) A4.29.2, by 24 persons having very low vision.

The authors would like to acknowledge the support of Vincent DeMarco, Deputy Director, Office of Engineering Evaluations, Federal Transit Administration (FTA), for support of this research through the Volpe National Transportation Systems Center (VNTSC). His ongoing support of research and technical assistance toward implementation of the Americans with Disabilities Act requirements for detectable warnings will contribute to safe and accessible transit for all persons.

The Massachusetts Bay Transportation Authority (MBTA) provided the setting for this research, installing additional lighting, at their own expense, for the laboratory area they had previously constructed for testing detectability of detectable warning surfaces. We would particularly like to thank William Bregoli, Martin McCartney, Paul Reynolds, and Lawrence Parretti for their support and assistance in designing, installing, and measuring illumination.

Patricia Ryan, Project Manager, VNTSC, provided valuable technical support throughout all phases of the project. Her good working relationship with key MBTA personnel helped to keep the project moving toward a successful conclusion.

Lee Tabor, A.I.A., provided figures for this report.

We would also like to thank Dennis Cannon, Architectural and Transportation Barriers Compliance Board, and John Brabyn, Smith-Kettlewell Eye Research Institute, San Francisco, for their assistance in conceptualizing this research and in interpreting its outcome. William T. Hathaway of the Volpe Center helped to assure the relevance and accuracy of the content of this report.

Finally, we would like to acknowledge the eager participation in this research of persons in the Boston area having low vision. It is only because of their commitment to accessible transit for all people that such research can take place.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2 = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2 = 0.09 square meter (m_2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (1)
1 pint (pt) = 0.47 liter (1)
1 quart (qt) = 0.96 liter (1)
1 gallon (gal) = 3.8 liters (1)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] ^oF = y ^oC

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yeards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (1) = 2.1 pints (pt)
1 liter (1) = 1.06 quarts (qt)
1 liter (1) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] ^oC = x ^oF

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

^oF	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
^oC	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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EXECUTIVE SUMMARY

Visual contrast of ten detectable warning surface/platform pairs was tested by 24 persons having very low vision, on an interior platform illuminated at 20 fc. Contrasts ranged from 25% to 86%. Light reflectance values for platform and warning surfaces were measured in foot-lamberts using a digital photometer. Contrast was calculated using the formula:

"Contrast = $[(B_1 - B_2)/B_1] \times 100$

where B1 = light reflectance value (LRV) of the lighter area and B2 = light reflectance value (LRV) of the darker area."
(ADA Accessibility Guidelines – ADAAG – A4.29.2-1991)

Tests included objective and subjective measures of visual detectability. Objective measures were accuracy (correct identification of the presence of a warning surface) and response time. Subjective measures were each participant's choice of the three most visually detectable contrasts, the one most visually detectable contrast, and the least visually detectable contrast.

RESULTS

Objective Measures

- All contrasts of 70% and above (as recommended by ADAAG A4.29.2) were highly detectable to persons having low vision.
- Contrasts from 40% to 69% were just as visually detectable as higher contrasts.
- There were no significant differences in visual detectability of contrasts ranging from 40% to 86%.
- A contrast of 25% was less visually detectable than contrasts of 40% or higher.
- There was a non-significant trend in the theoretically expected direction that contrasts in which the lighter surface is quite light (high in reflectance), are more visually detectable than contrasts in which the lighter surface is nonetheless relatively dark.

Subjective Measures

- The two contrasts in which the warning surface was safety yellow (ISO 3864) were those most frequently chosen as "most visually detectable,"even though their contrasts were 40% and 62%.

- The contrast of safety yellow with concrete was only 40%; nonetheless it was chosen as one of the two most visually detectable contrasts.

- The two highest contrasts (80% and 86%) were never chosen as "most visually detectable." Both included yellow detectable warnings of lower light reflectance value than the safety yellow.

- The contrast which was chosen as least visually detectable was lowest in light reflectance (a dark red warning adjoining a black Pirelli tile), though the contrast was 67%–highly visually detectable by objective measures.

CONCLUSIONS

- The specification (ADAAG 4.29.2) of a light-on-dark or dark-on-light contrast does not assure high visual detectability of detectable warnings by persons having low vision.

- The recommended (ADAAG A4.29.2) 70% contrast between a detectable warning and an adjoining surface appears adequate to provide high visual detectability, but this contrast should be further qualified by specification of the minimum reflectance of the lighter of the two surfaces.

- Specification of safety yellow (ISO 3864) could result in detectable warnings which are universally recognized as warnings, and which are reliably visually detectable and highly salient to persons having low vision, if a minimum contrast between the warning and adjoining surface is specified.

- A 40% contrast between a safety yellow (ISO 3864) detectable warning and an adjoining surface (concrete) provided excellent visual detectability. It is possible that even lower contrasts with safety yellow could still be visually detectable because of the exceptional salience of safety yellow.

RECOMMENDATIONS

- Determine whether detectable warnings are to be standardized warning signals.

- If detectable warnings are not to be standardized signals, determine the relationship between contrast and minimum reflectance of the brighter surface which determines those combinations of contrast and reflectance which result in reliable visual detection by persons having various levels of vision in various lighting conditions. Include this determination in standards requiring light-on-dark or dark-on-light.

- If detectable warnings are to be standardized signals, determine the minimum contrast with safety yellow (ISO 3864) which provides for reliable visual detection by persons having various levels of vision, in various lighting conditions. Specify that detectable warnings shall be safety yellow (ISO 3864), and specify a minimum contrast with the adjoining surface.

1. BACKGROUND

The Americans with Disabilities Act Accessibility Guidelines (ADAAG) require that detectable warnings "4.29.2...contrast visually with adjoining surfaces, either light-on-dark, or dark-on-light." The appendix contains the following recommendation:

> "A4.29.2 Detectable Warnings on Walking Surfaces. The material used to provide contrast should contrast by at least 70%. Contrast in percent is determined by:
>
> $$\text{Contrast} = [(B_1 - B_2)/B_1] \times 100$$
>
> where B_1 = light reflectance value (LRV) of the lighter area
> and B_2 = light reflectance value (LRV) of the darker area."

The visual contrast specified (4.29.2) and recommended (A4.29.2) in ADAAG is based on differences in lightness between warnings and adjoining surfaces, not differences in what we commonly refer to as color.

Three measurable qualities make up any color. Hue is the name by which we typically refer to a color, and it is defined by the wavelength of light coming from (either emitted by or reflected from) a source; e.g. light having a wavelength of 450 nm* will be perceived as blue, and light having a wavelength of 650 nm will be perceived as red. Value is the amount of light in a color, and it can be measured by a photometer. The LRV in the above formula refers to value, or the lightness of a surface, as indicated by measuring the amount of light reflected from that surface. The most common measure for this purpose is foot-lamberts (fL). Chroma or saturation is a measure of the purity of the hue, i.e. how different it is from white or gray (Munsell 1919; Haber and Hershenson 1980). Any color can be precisely described using any of several systems of notation which include notations for hue, value and chroma.

There are numerous factors in addition to hue, value and chroma which affect perception of visual contrast. In very low illumination, differences in hue are not detectable, while differences in value remain detectable at much lower levels of illumination (Ludel 1987). The nature of the light source also affects perceived color. Some light sources make the colors red, orange, green and blue appear grayish, while yellow is enhanced by most light sources, and made to appear grayish by none (McGuinness, W. J. and B. Stein 1977).

Perceived color and contrast are also affected by dirt on lighting elements and the surfaces from which light is reflected or through which it is transmitted. The surface texture of the material or finish also affects perceived difference in visual contrast, e.g., unglazed tile tends to absorb light, while glazed tile tends to reflect

---

* nm = nanometers, the unit of measure most commonly used for the wavelength of light.

light, and smooth textures tend to reflect light directly, while rough textures tend to scatter light. Furthermore—and more specific to the problems presented by detectable warnings—glare, installation methods, wear and maintenance can also affect contrast perception. Either glare or dirt may make the color of a surface indeterminable. Also, if color is not integral to a surface, it may be worn off. Joints between surfaces such as tiles, which are not consistent with those surfaces in all their visual properties, also may alter the over-all appearance of those surfaces, reducing the contrast provided by individual surface elements (tiles). Moreover, patching of both joints and surfaces may reduce visual contrast by creating inconsistencies in color and texture (Grayson 1993).

Both the ADAAG specification of light-on-dark or dark-on-light contrast and the recommended contrast percent have been criticized. Two organizations representing persons who are visually impaired (American Council of the Blind and Council of Citizens with Low Vision), as well as several scientists, have recommended that detectable warnings be yellow – specifically, the yellow (ISO 3864) identified by the International Standardization Organization for indicating hazards. The contention is that consistent use of a color which is already standardized for hazards will result in the fastest recognition and most reliable response to detectable warnings.

However, the Architectural and Transportation Barriers Compliance Board (Access Board), in preparing the ADAAG, opted to require a difference in lightness, without specifying color. This decision was based on the concern that if detectable warnings were a standard yellow, where light surfaces were used for platform or paving surfaces, the similar lightness of the warning and adjoining surfaces might reduce detection.

The 70% recommended contrast value appears to have been based on an Access Board-sponsored project on signage for persons having low vision (Georgia Institute of Technology 1985). However, it has been pointed out (Brabyn 1991) that "it is possible to obtain 70% contrast with a 10% reflectance letter on a 3% reflectance background," which might not, in fact, provide enough difference to facilitate reading. Therefore, perhaps minimum reflectances for lighter surfaces should be specified along with contrast values, for both signage and detectable warnings in order to provide for optimal reading or detection.

Spiller and Multer (1992) suggested that standardization of the light reflectance value and color of detectable warnings would be more consistent with the concept of a standardized warning surface, than the specification of "either light-on-dark, or dark-on-light," (ADAAG 4.29.2). Furthermore, they pointed out that if detectable warnings were yellow, a color frequently used as a warning signal, people having unimpaired vision would benefit from this information.

Some persons have questioned whether a 70% contrast is necessary for reliable detection, or whether a lesser contrast may be sufficient. Other persons have objected to the contrast value on the basis that it would prove too difficult to measure and maintain in the field.

1.1 PRIOR RESEARCH

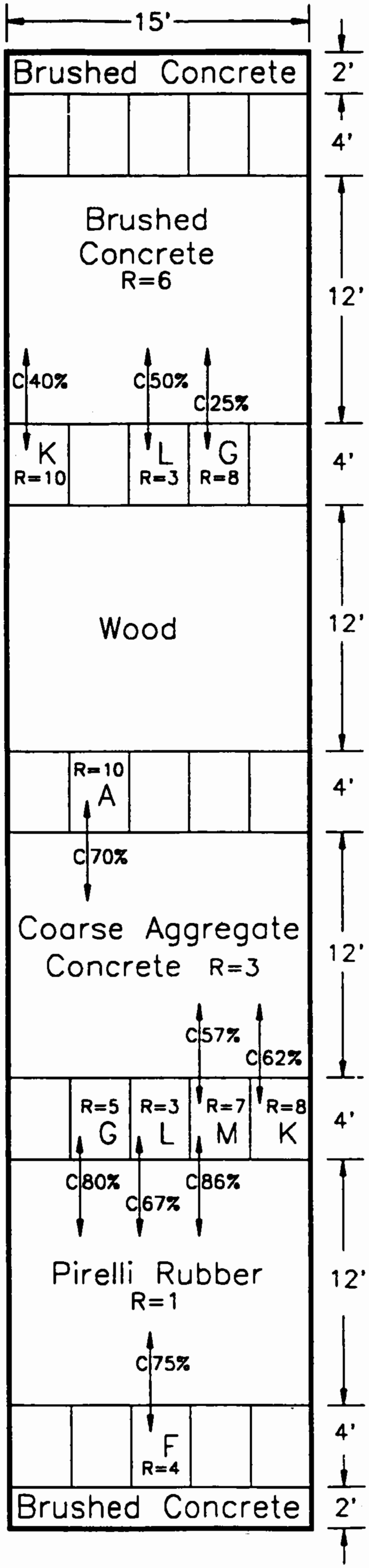
Templer, Wineman, and Zimring (1982), conducted the only known prior research investigating visual contrast of detectable warning surfaces by persons with low vision. Four persons having low vision tested detectable warnings which were painted with either solid colors or patterns of five hues, each at full saturation, and all having the same value. All participants had previously tested detectable warnings which were not painted. All research was conducted on a test track on which participants approached each warning from a distance of 7 feet to 24.5 feet. Participants, all of whom used a long cane as a travel aid, were asked to stop as soon as they detected a surface change (warning); then the stopping distance was measured (i.e., the position of the front of the forward-most shoe). Participants' stopping distances for painted warnings were significantly less than for unpainted warnings. However, there were no significant differences in stopping distance among the painted panels. This was not surprising, given the small number of participants, and the fact that hue was the only aspect of color which was varied. Nonetheless, it was clear from the work of Templer et al. (1982), that color contrast enhanced detectability.

1.2 GOALS OF THIS RESEARCH

The research undertaken in the project reported here was in response to a request by the Federal Transit Administration for assistance in refining the contrast specification for detectable warnings. It was conducted on a laboratory platform originally constructed by the Massachusetts Bay Transportation Authority (MBTA) for studying underfoot detectability of ten different warning surfaces in association with four different platform surfaces (Figure 1-1) (Bentzen et al. 1993). The research on visual contrast specifications conducted on this laboratory platform was constrained by the surfaces existing on the platform; it was not a full and systematic investigation into the perception of visual contrasts by persons having low vision. Nonetheless, the results will be seen to be informative in terms of specifications and recommendations for detectable warnings.

This project could realistically deal with only a few of the factors affecting contrast perception. Illumination was held as constant as reasonably possible, at 20 fc* , the minimum illuminance utilized by the MBTA (McCartney 1993). This was provided by new fluorescent fixtures and elements. Nonetheless, platform illuminance measured using a digital photometer (Quantum Instruments, Photo-meter 2) ranged from 12.5 fc along one end of the platform to 24.5 fc along the opposite end. As a result, warning surfaces which were included in more than one contrast

* fc = foot-candles, the unit of measure most commonly used for measuring the amount of light energy incident on a surface.



C = contrast in percent

R = light reflectance value in foot-lamberts

Letter designations of detectable warning surfaces are the same as those used in reports of underfoot detectability, and safety and negotiability. See Appendix A for names of manufacturers of each surface.

Figure 1-1. Laboratory platform for testing visual contrast of detectable warnings. (Platform originally constructed by Massachusetts Bay Transportation Authority, at old Broadway Station, Boston, for testing underfoot detectability of detectable warning surfaces.)

sometimes had a higher light reflectance value (luminance) in one location than in another. For example, the safety yellow surface (matched by Pantone 109u) which was used in the 62% contrast had a luminance of 8 fL** while the same surface, when used in the 40% contrast, had a luminance of 10 fL.

Ten contrasts were tested, representing a range of 25% to 86%, and having surfaces (platform and warning surfaces) ranging in luminance from 1 to 10 foot-lamberts as measured by a digital photometer (Photo-meter 2, Quantum Instruments) held three feet above each surface, and perpendicularly to it (i.e., aimed directly down). These visual contrasts were a combination of three platform surfaces (brushed concrete, coarse aggregate, and black Pirelli tile), and six warning surfaces. In one contrast participants were standing on a light surface, attempting to see a dark surface (a dark-on-light contrast), and in nine contrasts they were standing on a dark surface, attempting to see a light surface (a light-on-dark contrast). (See Figure 1-1.)

Most light measurements reported in this project are rounded to the nearest whole number, although the photometer used in this project is actually a very precise instrument. The level of precision reflected in this report was considered to be appropriate to realistic field conditions of this research, which were similar to conditions which would be faced on-site in transit facilities. Luminance of each surface observed in this project varied according to distance from and brightness of walls, as well as distance from light sources, uneven surface textures, and some dirt. Therefore, inclusion of more precise values in this report was considered to be more misleading than helpful. Luminance was measured directly above each detectable warning surface, as this is readily understood and easy to do in the field. The luminance measured directly above the warning surface is greater than that which actually reaches the eyes of perceivers as they approach warning surfaces. A more scientifically correct approach would be to measure luminance from the perspective of a viewer at different distances, but this requires more sophisticated equipment and procedures.

Likewise, the color designation system used in this report is based on the Pantone color system, one which is readily available and used by the building industry, rather than a more precise system such as the Munsell color notation system, which is more appropriate for scientific measurement. The Pantone system provides a number identifying each color, not a name. Color names are suggested here by the researchers as an aid to the reader in visualizing the approximate colors of the surfaces. The Pantone numbers reported in Table 1-1 were obtained on the experimental platform, as lighted for the experiment, by having two observers with normal color vision match standard Pantone color chips to each warning surface. This is not a highly accurate system of color matching, to say the least, but it is representative of field practices.

** fL = foot-lamberts, the unit of measure most commonly used for measuring light reflected from surfaces.

Hues of detectable warning surfaces varied as did their luminance. Five of the six warning surfaces could be roughly described as some shade of yellow, though the precise hues differed considerably. The sixth surface was grayish red. More precise descriptions of all surfaces are given in Table 1-1.

Table 1-1. Surfaces Included in Visual Contrast Test

Contrast Percent	Illuminance at Each Test Site	Warning Surface			Platform Surface		
%	Illuminance fc	Description	Luminance fL	Reflectance %	Description	Luminance fL	Reflectance %
86	21.8	Pantone 611u (Grayish Yellow Green)	7	32	Pirelli tile	1	5
80	20.4	Pantone 141c* (Dark Orange Yellow)	5	24	Pirelli tile	1	5
75	12.5	Pantone 1245u (Light Yellowish Brown)	4	32	Pirelli tile	1	8
70	22.3	Pantone Process Yellow u (Primary Yellow)	10	45	Coarse Aggregate	3	13
67	19.5	Pantone 187u (Grayish Red)	3	15	Pirelli tile	1	5
62	23.5	Pantone 109u* (Federal Safety Yellow)**	8	34	Coarse Aggregate	3	13
57	20.8	Pantone 611u (Grayish Yellow Green)	7	34	Coarse Aggregate	3	14
50	20.3	Pantone 187u (Grayish Red)	3	15	Brushed Concrete	6	30
40	24.5	Pantone 109u* (Federal Safety Yellow)**	10	41	Brushed Concrete	6	24
25	22.2	Pantone 141c* (Dark Orange Yellow)	8	36	Brushed Concrete	6	27

* Due to slight differences in illumination, warning surfaces which were used in more than one contrast did not always have the same luminance in both locations.

** The color of this surface is equivalent to ISO 3864 and Federal Safety Yellow color 33538.

All surfaces were moderately clean. The laboratory was in an area where construction was taking place, creating dust and dirt on the surfaces. These surfaces were professionally cleaned prior to testing, and were swept clean by experimenters several times over the five weeks during which testing was conducted.

The surfaces had been installed between 4 and 12 months prior to testing, and subjected to relatively little traffic. Therefore, there was little wear on any surface.

The surfaces all had truncated domes corresponding approximately to the dimensions specified in ADAAG 4.29.2, but they varied in material or finish, some being smoother or more glazed than others.

2. METHOD

2.1 SUBJECTS

Twenty-four participants were selected based on the following functional vision criteria, obtained from self-reports. They had sufficient vision to enable them to tell where a bright light was coming from (i.e., "light projection"), were rarely able, or unable, to read signs – even under optimal conditions (i.e., distance, sign size, contrast, and lighting), were unable to reliably see platform edges in interior transit stations, and were unable to reliably see where curb ramps end and streets begin. Information concerning participant attributes was obtained during an initial telephone interview. Eight of the participants were males and 16 were females. The age range was 23 to 69 years , with a mean age of 48 years. Fifteen of the participants used a long cane while traveling, two used a dog guide, two used either a long cane or a dog guide, and five participants traveled without the use of any aid. Participants were paid $20 for each experimental session. Participants for the studies were obtained through the help of three agencies for persons who are visually impaired, organizations of individuals who are blind, announcements in agency and/or organization newsletters and telephone information services, and by word-of-mouth.

2.2 PROCEDURE

Participants were tested individually in one hour sessions, in which they completed 40 trials. On half of the trials participants viewed contrasts and on half of the trials they viewed foils (trials in which warning surfaces were covered up). Each contrast and each foil was viewed from distances of both 4 feet and 8 feet.

A 3′ x 4′ cardboard frame with a 2′ x 2′ cut out (see Figure 2-1) was used to direct participants' attention to each warning surface. In addition, warning surfaces adjacent to the test surface were obscured by fabric which matched the adjoining platform surface in color. Foils were provided by placing additional pieces of fabric, matching each platform surface, over warning surfaces. The cardboard frame was used on both test trials and foils.

Participants were told that they would be walking on a large level platform having four surface materials likely to be used for platforms in a transit station and that they would be viewing six other surfaces, from these platform surfaces, that might be used as detectable warning surfaces on a transit platform edge.

Participants, who were asked to close their eyes, were guided to each test site by an experimenter. They were positioned with their backs toward the test surface, or foil, and stood with their eyes closed, until the fabric and frame were in position.

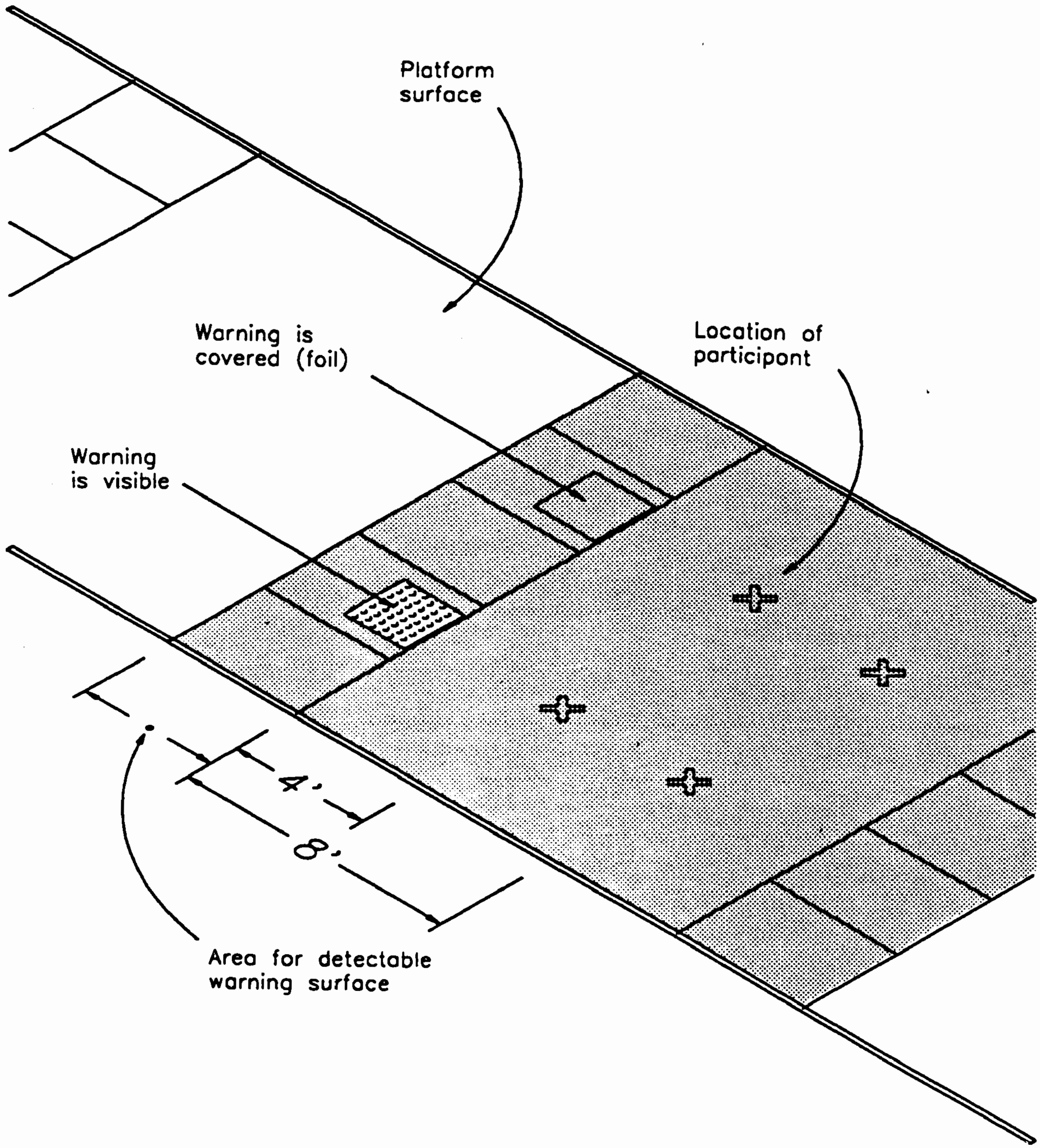


Figure 2-1. Isometric view of experimental set-up, showing participant locations, a condition in which the detectable warning is visible, and a condition in which the warning is covered, i.e., a foil.

Next, experimenters guided participants to face directly toward either the test surface or the foil and then tapped their shoulders. At this time participants opened their eyes, looked in front of them, and as quickly and accurately as possible responded "yes," meaning they saw a difference between the surface they were viewing and one that they were standing on, or "no," they did not see a difference between the two surfaces.

This procedure was repeated until all ten contrasts and foils had been tested from two distances – eight feet and four feet. Trials were grouped by platform surface, which was randomized across subjects. Within each platform surface, warning surfaces and foils were randomized, as was viewing distance.

Participants were familiarized with the task and procedure by completing four practice trials from the wood platform surface, which was not used in the actual study. The four practice trials consisted of two contrasts and two foils. The presence and size of the frame was explained, and participants were allowed to feel the 2′ x 2′ frame if they desired.

Initially it was planned only to obtain accuracy data (reports of the presence or absence of contrast). However, after the first eight participants had completed the procedure it became apparent that anticipated differences in detectability of the various contrasts were not revealed in the accuracy data. At the same time, participants were volunteering strong preferences for some contrasts and dislike of others. Therefore, two additional measures were added to the data.

First, response times were obtained by starting a stop watch when participants opened their eyes to look at the contrasts (or foils), and stopping the watch as they began to utter their responses ("yes" or "no"). Second, subjective judgments were systematically obtained following objective testing. Specifically, participants were asked which three, of the ten contrasts that had been tested, were the easiest to detect, which one was the easiest to detect overall, and which one was the hardest to detect overall.

3. RESULTS AND DISCUSSION

3.1 PERFORMANCE DATA

The mean percentage of correct responses for each contrast at each distance is presented in Table 3-1. It can be seen from the bottom row that detectability, as indicated by correct responses, ranged from 71.8% to 100%, with all but one surface having better than 90% detectability. Surfaces having contrasts from 40% to 86% all had better than 90% detectability, while the 25% contrast had only 71.8% detectability.

Table 3-1. Mean Percentage of Correct Responses as a Function of Contrast, Luminance, and Distance

Surface Characteristics Contrast	25%	40%	50%	57%	62%	67%	70%	75%	80%	86%
Luminance (in fL) for the Two Surfaces Creating Each Contrast	8:6	10:6	6:3	7:3	8:3	3:1	10:3	4:1	5:1	7:1
Correct Responses in % at 4 feet	82.6	95.6	91.3	100	100	100	100	91.3	100	100
at 8 feet	60.9	91.3	95.6	95.6	100	91.3	100	91.3	100	100
Collapsed Across 4′ and 8′	71.8	93.3	93.3	97.8	100	95.5	100	91.3	100	100

Two one-way within-subjects Analyses of Variance (ANOVA) were conducted – one for contrast and one for distance. (Given the nature of the data, i.e., there was only one datum per contrast/distance combination, it was not appropriate to conduct a 2 x 2 Analysis of Variance.) Results of the ANOVA for contrast showed a significant effect ($F(9, 198) = 5.267$, $MSe = .032$, $p < .001$). A Tukey (HSD) post hoc analysis showed the 25% contrast to be significantly less detectable ($p < .01$) than any of the nine other contrasts, which did not significantly differ from one another. Thus, while contrast did affect detectability in this research, the lowest contrast (25%) accounted for all of the statistical significance.

The ANOVA on the distance data showed a significant effect of distance ($F(1,22) = 6.642$, $MSe = .002$, $p < .02$), with contrasts being significantly less detectable from eight feet than from four feet (See Table 3-1).

A planned contrast between low contrast surfaces (defined as contrasts below the 70% contrast recommended in ADAAG A4.29.2) and high contrast surfaces (defined as contrasts equal to or greater than 70%), was also conducted as a specific test of the ADAAG recommendation. This analysis showed a significant difference between the two contrast groups, with the low contrast group being significantly more difficult to detect than the high contrast group ($F(1, 198) = 5.987$, $MSe = .032$, $p < .02$). This finding, that contrasts of (ADAAG) recommended levels are more detectable by persons with low vision than lesser contrasts, supports the recommended 70% minimum contrast value of A4.29.2. However, observation of the data suggested a particular drop-off in performance occurring at a contrast level of 25%. Therefore, a second planned contrast between the 25% contrast and the other nine contrasts (40%-86%) was conducted. Results showed that the 25% contrast was significantly different from the other nine contrasts ($F(1, 198) = 40.761$, $MSe = .032$, $p < .001$).

Thus, all analyses show that contrasts from 40% to 86% were all detected at a rate which was not significantly different from 100%. This suggests that a 70% contrast between transit platforms and detectable warnings may not be necessary for high detectability.

In order to examine the relationship between contrast and reflectance a matrix was created relating contrast to reflectance of the brightest surface in each pair (See Table 3-2). The matrix includes contrasts from 0% to 100%, and reflectances from 0% to 50%. Reflectances were computed as the percentage of incident light (illuminance, measured in foot-candles) which was reflected from warning and platform surfaces (luminance, measured in foot-lamberts). If, as was suggested with regard to signage (Brabyn 1991), a 70% (or higher) contrast achieved by surfaces having low reflectance values will nonetheless result in low detectability, we would expect pairs of surfaces which were similar in contrast, but in which the reflectances were quite different, to differ in detectability.

Within the contrast/reflectance matrix, it can be seen that there are four contrast levels at which two contrasts were tested in this project – 50-59%, 60-69%, 70-79% and 80-89%. Within each of these four contrast levels, the two tested contrasts differed from one another in that the reflectance of the lighter surface in one contrast was greater than the reflectance of the lighter surface in the other contrast. In three of these four contrast levels, the mean detectability was greater for contrasts having higher reflectance values than for contrasts having lower reflectance values; in the fourth contrast level, the mean detectability of both contrasts was equal at 100%.

Thus, while there was no significant difference in detectability between pairs of contrasts tested at any contrast level, the results are in the expected direction. While there is necessarily some limit of reflectance of the lighter surface in any contrast which would be highly detectable, this lower limit has not been identified in this project.

Table 3-2. Contrast/Reflectance Matrix Showing Mean Detectability for Each Contrast Tested

Percent Contrast*

0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100	Percent Reflectance of the Brightest Surface (fL/fc x 100)
										46-50
				r=41:24 d=93.3			r=45:13 d=100			41-45
		r=36:27** d=71.8								36-40
					r=34:14 d=97.8	r=34:13 d=100	r=32:8 d=91.3	r=32:5 d=100		31-35
					r=30:15 d=93.3					26-30
								r=24:5 d=100		21-25
										16-20
						r=15:5 d=95.5				11-15
										6-10
										0-5

r = ratio of reflectances creating each contrast.

d = mean detectability of each contrast, collapsed across 4 foot and 8 foot viewing distances.

* Contrast ratios were derived from the luminance values (in foot-lamberts) of each platform surface/warning surface contrast. Cells in which reflectance ratios and mean detectability are shown include all contrasts tested in this project (a relatively small sample of the entire matrix).

** The only contrast which was detected significantly less often than the others, which were essentially equal.

One may ask how it is that contrasts comprising materials having quite low reflectance values were nonetheless highly detected in this experiment. Three possible explanations come readily to mind. First, it may be that the vision of participants was actually quite good, and that, given no time limit, there was no reason not to expect them to see these contrasts. However, participants were representative of the population of persons who have low vision who are expected to have difficulty with visual detection of contrasts, i.e., two criteria for self-selection were that participants sometimes had difficulty visually detecting platform edges and/or that they sometimes had difficulty telling where curb ramps end and streets begin.

Second, it may be that too few subjects were tested. However, in order for detection rates of 100% and 95.6% to be significantly different, these rates would have to represent the performance of at least 171 participants. Even for detection rates of 100% and 91.3% to be significantly different, a minimum of 85 participants would be required. Thus, it might be possible to find significant differences in the expected direction by testing more participants.

Third, detecting a detectable warning from distances of 4′ to 8′, created by the juxtaposition of two surfaces which are quite low in reflectance values, but in which the warning is at least 2′ x 2′ in area, may require minimal vision. Undoubtedly, the task performed here is a simpler task than reading messages on signs in which both background and message are low in reflectance values. Therefore, while there must be some function that describes the lower limit of contrast and reflectance of the brighter surface which results in high detectability, this project has not identified that function. The lower limits of contrast and reflectance tested in this project, and which yielded detectability rates which were not significantly different than 100%, were a contrast of 40%, comprising surfaces having reflectances of 41% and 24%, and a contrast of 67%, comprising surfaces having reflectances of only 15% and 5%.

A two-way within-subjects ANOVA conducted on the response times showed marginally significant main effects of both contrast, ($F(9, 135) = 1.897$; MSe = 13.768, $p < .06$), and viewing distance, ($F(1, 15) = 3.519$; MSe = 2.349, $p < .08$), which were qualified by a marginally significant interaction between contrast level and viewing distance ($F(9, 135) = 1.757$, MSe = 2.060, $p < .08$). A simple effects test of contrast and viewing distance, however, showed no significant differences in response times. Neuman-keuls tests found no significant effects of response time as a function of either contrast or distance. Thus, response time is not a particularly sensitive measure in this case, revealing no significant differences in any contrasts or between viewing distances.

Of the total 480 foil trials in the experiment, participants reported seeing a contrast on 43 trials (9%). These foils can best be conceptualized as "distracters" in this experimental paradigm. It was not appropriate to use performance on foils in a signal detection analysis, as there was always some minor difference between platform surfaces and the fabric covering warning surfaces. Thus, there was always a possibility that a participant actually perceived even this minimal difference.

3.2 SUBJECTIVE DATA

The subjective data were analyzed to determine which visual contrasts participants thought were the most detectable. Not all participants were asked to make subjective judgments.

For the 16 participants who indicated their top three choices for "best" visual contrast, the number of times a contrast was chosen was tallied and a percentage computed. These percentages are presented in Table 3-3 and are rank ordered from the contrast most often included in the top three to the one least often included in the top three. (Note: Where tie scores occurred, ordering in the table is not meaningful).

Table 3-3. Rank Order of Visual Contrasts and Reflectance Levels That Were Chosen Among Participants' Top Three Choices for Detectable Warning Surfaces

Contrast Level	Percentage of Times Chosen by Participants
62%	29.17
40%	27.08
70%	18.75
50%	6.25
75%	4.17
57%	4.17
86%	0.00
80%	0.00
67%	0.00
25%	0.00

Of the ten contrasts tested, five were chosen by 18 participants as the single most detectable contrast. These results are presented in Table 3-4 in rank order from most chosen to least chosen.

Table 3-4. Rank Order of Visual Contrasts and Reflectance Levels That Were Chosen by Participants as First Choice or "Best" Contrast

Contrast Level	Percentage Chosen as First Choice
62%	39%
40%	33%
50%	11%
70%	5.5%
75%	5.5%
"none really"	5.5%

It can be seen in Tables 3-3 and 3-4 that the 62% contrast and the 40% contrast were much more frequently included in the three contrasts subjectively judged to be the most detectable, and were also the two contrasts most frequently chosen by participants as the single best contrast. The warning surface in both of these contrasts was safety yellow (Pantone 109u), the Pantone color which corresponds most closely with ISO 3864 and Federal Standard 33538. Note that these two contrasts were both below the recommended 70%, and that, in terms of the objective data, they were detected as well as the warnings included in contrasts of 70-86%. Also note that in the 40% contrast, the yellow warning was detected in association with the lightest platform included in these contrasts, i.e., new brushed concrete.

It should also be pointed out that the two highest contrasts, 80% and 86%, were never selected as the most detectable, nor was either contrast included in the sets of three contrasts judged by participants to be most detectable.

Of the ten contrasts tested, four were chosen by 18 participants as the worst choice, which was defined as "a surface participants would not like to see put down on the edge of a transit platform because it is either undetectable or unreliably detectable." The percentages of times each contrast was chosen as "worst" are presented in Table 3-5.

Table 3-5. Rank Order of Visual Contrasts and Reflectance Levels That Were Chosen by Participants as "Worst" Contrast

Contrast Level	Percentage Chosen as Worst Choice
67%	50%
25%	33%
75%	11%
50%	5%

The 67% contrast, chosen as worst by 50% (9) of the participants, was provided by two relatively dark surfaces, a grayish red (Pantone 187u) warning against a black Pirelli tile platform. Although objective detection rates indicate that detectability of this contrast was not significantly different than 100%, more participants nonetheless judged it as worst than judged the 25% contrast as worst. The 25% contrast was provided by two surfaces which were both lighter than those in the 67% contrast. This suggests that subjectively, as well as objectively, contrasts between surfaces having high light reflectance values are more detectable than similar contrasts between surfaces having low light reflectance values.

Subjective judgment of greatest detectability appears to be based more on color than on contrast in light reflectance. The warning surfaces in the two contrasts judged to be most detectable were both safety yellow (Pantone 109u), although one contrast was 62% and the other was only 40%. Although the safety yellow surface was among the detectable warning surfaces having the highest reflectance, detectable warnings having reflectances of equal or greater value, and for which the contrast percents were also higher, were subjectively judged as less detectable. Therefore, the subjective preference for safety yellow as most detectable could not have been based either on its high reflectance, or the fact that it was used in particularly high contrast locations.

There are three possible explanations for the preference for contrasts in which the detectable warning was the yellow closest to the ISO standard color (3864) (i.e., safety yellow) for marking hazards. First, the preference may have been prejudiced by participants' knowledge that this yellow had been recommended by consumer groups as a standard color for warnings. While there was no systematic control for such knowledge, it was known that none of the research participants had been active in organization policy discussions regarding this issue. Moreover, although a few participants may have been aware that an organization of which they were a member advocated for yellow detectable warnings, it is unlikely that they would have known which of the yellows in this test was the yellow proposed by their consumer group.

A second possible explanation of subjective preferences for contrasts in which the warning was safety yellow (Pantone 109u) could be that participants already associated this particular yellow with hazards because of its common use for this purpose.

A third possible explanation is that safety yellow (Pantone 109u) was more salient, possibly because it is more saturated, than any other color tested. It is well known that the normal eye is more sensitive to some colors than others, even when value and chroma are held constant (Haber and Hershenson 1980). In particular the normal human eye is most sensitive to greenish yellow. However, no greenish yellow surface having the same value and chroma as safety yellow (Pantone 109u) was among the contrasts tested in this research. Thus, it is possible that a color exists which would be even more salient than safety yellow.

4. SUMMARY AND CONCLUSIONS

Ten contrasts ranging from 25% to 86% were tested for detectability by 24 persons who report themselves to be legally blind and to have some difficulty seeing transit platform edges and/or the junction between curb ramps and streets. Only one contrast (25%) was detected significantly less frequently than the others (ranging in contrast from 40% - 86%), which were all equally detectable at a level not statistically different from 100%. Thus, contrasts somewhat less than the 70% contrast recommended in ADAAG A4.29.2 may, nonetheless, be highly detectable by most persons having low vision.

Both human performance and subjective data support the notion that contrasts in which the lighter surface is of low reflectance are less detectable than similar contrasts in which the lighter surface reflects more light. However, there was insufficient data in this research to specify the lower limits of contrast and reflectance which would result in high detectability. Further research, particularly concentrating on low contrast/reflectance combinations, could determine this limit more precisely, providing data on which to base the addition of minimum reflectance values to the recommendations of ADAAG A4.29.2.

Subjective preference for the two contrasts in which the detectable warning was safety yellow (Pantone 109u), despite the relatively low value of those contrasts (40% and 62%), suggests that this color was more salient to persons with low vision than the other colors tested. While this research does not reveal the reason for the subjective superiority of safety yellow, its strong preferability, coupled with its high objective detectability even in contrasts as low as 40%, indicate that specification of safety yellow (ISO 3864) for detectable warnings could result in excellent visual detectability, as well as providing a standard color which already has international recognition for warnings. However, while the safety yellow surface was highly detectable in both contrasts used in this research, it is possible to envision contrasts in which safety yellow would be paired with a surface which would be too similar, and which would, therefore, result in low detectability. Therefore, if it is desirable to specify safety yellow as the color for detectable warnings, this specification should be supplemented by specification of the minimum contrast in which it can be used. This research indicates that safety yellow is highly detectable in contrasts as low as 40%.

Future research should be conducted under higher and lower illumination than the 20 fc used in this research, to be certain that the results are generalizable across different levels of illumination. Future research should also include persons having unimpaired vision.

This research has demonstrated that sufficiently accurate measurement of light reflectance values of detectable warning surfaces can be readily accomplished in the field using a digital photometer.

APPENDIX A

Sources of Detectable Warnings*

Source	Surface
Advantage Metal Systems 685 Oak Street, Suite 13-I Brockton, MA 02401	**M**
Carsonite International 1301 Hot Springs Road Carson City, NV 89701	**A**
Cote-L Enterprises 1542 Jefferson Street Teaneck, NJ 07666	**L**
Crossville Ceramics P.O. Box 1168 Crossville, TN 38557	**F**
Rapidcrete, Inc. P.O. Box 16 Syracuse, NY 13205	**K**
Terra Clay Products P.O. Box 992 6 Industrial Blvd. Roanoke, AL 36274	**G**

* Letter designations of detectable warning surfaces are the same as those used in reports of underfoot detectability, and safety and negotiability.

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