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# Classifying Colored Bar Codes to Predict Scanning Success

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## Overview

The theory and methods of bar code print quality verification have progressed over the last decade. However, there is precious little in the literature with respect to colored bar code symbols. A search of the Institute for Scientific Information Citation Database revealed only one published article (Agroskin & Golubovskii, 1996) related to the effect of color on bar code symbol contrast. A search of the Automatic Identification Manufacturers' (AIM) and Institute of Electrical and Electronic Engineers' (IEEE) jointly sponsored Workshop on Automatic Identification Advanced Technologies conference proceedings revealed one related paper (Sutton, 1999). In most cases, the literature gives general guidelines, but limited research has been conducted to help the practitioner make educated choices on bar-space color combinations. Agroskin and Golubovskii concur, stating that information regarding the spectral properties of bar codes and the spatial distribution of reflected light is "absent in the available literature" (p. 229). The purpose of this research is to propose a standard method of objectively classifying colored bar codes to help predict, before printing, how well a bar code symbol might perform after it is printed. To do this, an older, well-established method of measuring color will be applied to the field of colored bar code print quality verification.

## Introduction

The lynch pin of any successful organization, operating on the tenets of lean manufacturing or lean logistics, is information. Accurate, timely information drives the corporate decision-making process. Accuracy and timeliness are both required. If accurate information takes too long to process, an organization is forced to operate in a historical mode, missing valuable business opportunities. On the other hand, information processed quickly, but inaccurately, causes poor business decisions.

Automatic identification and data capture (AIDC) evolved over the years to help improve both timeliness and accuracy of information needed to make strategic and tactical business decisions. Just as logistics provides time and place utility for goods within the supply chain (Coyle, Bardi, & Langley, 1996), AIDC provides time and place utility for critical data within a company and, in some cases, between supply chain partners.

According to Dunlap (1995), the goal of AIDC is to immediately identify physical objects with 100% accuracy and to pass this information to the host computer for instantaneous decision making. Perhaps the most familiar, and certainly the most predominant, form of AIDC technology is bar code.

Over the past 30 years, linear bar codes quietly infiltrated and permeated the retail, manufacturing, and logistics industries. Their popularity, in part, is a direct result of the speed and accuracy by which data are entered into a computer for processing and decision making. In simple terms, information is encoded in the widths of the bars and spaces. As a scanner passes over the bars and spaces, it "senses" the amount of light reflected back to it. The amount of time necessary to scan a given bar or space determines its width and is converted into digital information which is meaningful to a computer (Palmer, 2001).

## Bar Code Verification

A successful decode depends greatly on how well a scanner can distinguish the dark bars from the lighter spaces. In essence, there must be sufficient contrast between the bars and spaces for a scanner to read the printed symbol successfully and reliably (Collins & Whipple, 1994; Harmon, 1994; Palmer, 2001). As bar codes evolved since the early 1970s, so too did the methods by which to evaluate a symbol's print quality. The branch of bar code data capture that involves measuring and evaluating bar code print quality is called bar code verification.

In 1983 the American National Standards Institute's (ANSI) X3A1 Technical Subcommittee on Optical Character Recognition (OCR) began studying the issue of bar code print quality. The committee's goal was to develop a technically sound method of evaluating bar code print quality that emulated the operation of a bar code scanner (Allais, 1995; Mullen, 1994). After numerous meetings and discussions over the next seven years, the Bar Code Print Quality Guideline – ANSI X3.182 was published as the new bar code print quality method.

The new guideline was a considerable leap forward for the science of bar code verification. Where the traditional method evaluated bar codes according to how they were seen by the human eye, the ANSI guideline was written around how a scanner views them. Tedesco (1992) described the ANSI method as "emphasizing how well a symbol will scan rather than how well a symbol is printed" (p. 34). Logically, the ANSI method focuses on several reflectance parameters.

The first attribute to affect a symbol's overall grade is symbol contrast (Data Capture Institute, 1994; Palmer, 2001). Symbol contrast $\left(SC = R_{Max} - R_{Min}\right)$ measures the difference in reflectance between the dark bars and the lighter spaces. If enough contrast exists, the scanner can distinguish between the bars and spaces. Two factors that also affect a bar code symbol contrast are the color of bars and spaces and the wavelength of light used to scan the symbol.

## Colored Bar Codes

The degree of bar code contrast is a primary concern for designers and printers of labels and packaging that employ bar code symbols. Many experts agree that ideally, the blackest possible bars should be printed on the whitest possible background (Collins & Whipple, 1994; Erdei, 1993; Harmon, 1994). Harmon concedes that, in practice, this is not the case. A casual inspection of the items that line the shelves of a typical grocery store bears this out. Bar code symbols are printed on a variety of substrate materials and in many different colors to coincide with a package's color scheme.

The issue of color is significant for those who design labels or packages that use bar codes. Although people can distinguish between most color combinations, they interpret colors differently than does a scanner (Fox, 1991; Palmer, 2001; Stamper, 1989). As a result, several guidelines are available similar to Erdei's (1993) and Stratix's (1995), which show various color combinations that work best for printing bar codes – bar codes that will have enough contrast for successful scanning. For example, Erdei suggested four bar colors when illuminated by 633 nm red light: black (most suitable), blue (with high cyan content), green (with low yellow content), and brown (dark only with low red content). In addition, he suggested four background (space) colors: white (most suitable), yellow (very good), orange (with no components from other colors), and red (with no components from other colors).

Based on general color theory, Erdei's (1993) and Stratix's (1995) suggestions are helpful and practical. Erdei suggested that one should view the color combinations' contrast "through a Wratten 26 red filter in the same way a scanner will look at them" (p. 131). Harmon (1994) made a similar suggestion. He noted that when viewing with a red light source (i.e., helium-neon and visible red laser diodes), bars printed in red, yellow, orange, reddish-purple, and reddish-brown will not appear sufficiently different from the white spaces.

## The Issue of Color

When ANSI (American National Standards Institute, 1990) published the Bar Code Print Quality Guideline, they specified the optical geometry and general method for verifying bar code print quality. Their premise was that bar codes are primarily printed black on white – the ideal situation. They recognized colored bar codes existed – their method works equally well for black on white symbols or for colored symbols. However, determining all possible acceptable color combinations was beyond the scope of the ANSI guideline.

Why classify bar code colors? It's one thing to know that greens and blues reflect red laser light poorly and, therefore, perform well as bars and not well as spaces. Where does one draw the line between the color names they assign to an object? Where is the distinction between bluish-green and greenish-blue? Assigning color names to an object becomes quite tricky because of the human perception involved in identifying a colored object. When a person assigns a color name to an object, they do it through the lens of their personal experience, which understandably varies from individual to individual. Objectively classifying or grouping colors (hues) gives a better indication of how well that hue will reflect light. If we know a bar code's (bars and spaces) chromaticity and reflectance properties, we can determine symbol contrast and better predict how well the bar code will scan.

To bridge the gap between subjectivity and objectivity, the Optical Society of America's Committee on Colorimetry (1963) defined the psychophysical aspects of color, which involve relationships between physical stimuli and the sensory or perceptual responses to these stimuli. They clarified that these psychophysical relationships are definitions, in physical terms, of concepts derived from the subjective human responses to physical stimuli.

For example, a color can be defined by matching an object with a known spectral distribution to an object with unknown color. The object with a known spectral distribution can be expressed in terms of wavelengths, which are physical quantities. However, "matching" the colors of both objects to define equivalence is subjective – clearly psychological. The relationship between the two, which defines the color, is psychophysical.

This psychophysical nature of color is the basis for the International Commission on Illumination's (CIE) method of color specification. The CIE explains that the stimulus for color is provided by the proper combination of a source of light, an object, and an observer (Billmeyer & Saltzman, 1981) and attempts to tell us how a color might be reproduced rather than how it might be described (Rigg, 1987).

The basis for the CIE system is the trichromatic generalization. The trichromatic generalization states that over a wide range of observation conditions, many color stimuli can be matched completely by additively mixing some combination of three primary lights (Wyszecki & Stiles, 1982). The set of primary stimuli can be any three (i.e., red, green, and blue), as long as they meet one condition: mixing two primary stimuli will not produce the third.

The CIE system allows us to describe color in quantifiable terms. An object's color may be described as a specific point, defined by chromaticity coordinates, within a two-dimensional color space. Quantifying object color is important to bar code verification. Chromaticity coordinates facilitate classifying colors into relatively homogeneous groups according to dominate wavelength and are necessarily involved in describing or measuring color.

## *Measuring Color*

Contrary to most people's thinking, color is not a characteristic or inherent quality of an object (Chamberlin & Chamberlin, 1980; Committee on Colorimetry, 1963; Sharkey, 1991). Although people commonly associate an apple with the color red, the apple is not inherently red. Rather, the apple's physical make-up is such that it absorbs some portions of the visible spectrum and reflects others. Because people normally see objects in daylight, the color appearance under daylight conditions is how we tend to assign a color name to objects. We see an apple as red because it reflects light from the red end of the visible spectrum. However, if the apple is illuminated with a light source that doesn't contain "red" wavelengths, like sodium light, then the apple will appear gray or black.

The color of light illuminating an object is fundamental to bar code verification. The issue is not how people view the bar code, but how the bar code scanner "views" it. If a bar code is illuminated with different light sources, then the reflectance from the bar code will understandably vary based on the light source. Bar code scanners detect the amount of light reflected from a symbol independently from human color perception. At the same time when we view a bar code symbol under some form of white light, the scanner illuminates the symbol with a different colored light source, presumably a visible red laser scanner.

Since bar code colors are designed and specified by people, there exists a need to describe and classify colors objectively, according to the way people see them. Once classified, bar code symbol contrast can be evaluated to determine the overall effectiveness of a specific color group.

One way to define or measure color is based on spectrophotometry. Spectrophotometry involves a wavelength-by-wavelength measurement of the light transmitted or reflected by a sample or emitted by a light source (Wyszecki & Stiles, 1982). The output is in the form of a curve, called a spectral distribution. This distribution shows how the spectral composition varies across the visible spectrum (at discrete wavelength intervals) when illuminated by a specific illuminant.

A spectrophotometer's measurements alone do not tell what a color looks like. However, these measurements provide the basic data – spectral reflectance values at each wavelength over the visible spectrum – from which one can determine the color's appearance from agreed upon conventions.

## *A Method of Classifying Colored Bar Codes*

The colorimetry literature clearly reveals that the CIE system is the method of choice for measuring and classifying colors, whether in social science or industrial-technical disciplines (Committee on Colorimetry, 1963; Hunt, 1987; Judd & Wyszecki, 1975; Wyszecki & Stiles, 1982). The CIE system is a color measurement method independent of any one person. The CIE method produces a numerical description that gives an unambiguous definition of a color, representing the sensation that color would have on an average observer. The method involves a combination of three components: observer, light source (illuminant), and object.

## *Standard Observer*

To define a standard observer, the CIE used a number of people, who were not color deficient, to match colors additively under standard viewing conditions. Each observer viewed a color stimulus shown on one screen through a 10° field of view. While viewing the stimulus, the observer adjusted the intensities of three primary lights (R, G, and B), projected onto an adjacent screen, until the colors matched (Figure 1). The average of these results, $\bar{x}_\lambda$, $\bar{y}_\lambda$, and $\bar{z}_\lambda$, determined the spectral tristimulus values of the standard colorimetric observer.

## *Standard Illuminant*

The CIE adopted several standard illuminants over the years that correspond to typical lighting situations. Most notable are the D illuminants ($D_{55}$, $D_{65}$, and $D_{75}$). These illuminants are intended to represent daylight at all wavelengths between 300 and 830 nm. For general use and in the interest of standardization, CIE recommends using $D_{65}$, which represents average daylight (Berger-Schunn, 1994; Clulow, 1972; McDonald, 1997). Illuminant $D_{55}$ represents yellower daylight (sunlight plus skylight); $D_{75}$ represents bluer daylight (north skylight).

One shortcoming of the set of D illuminants is that no method was specified for reproducing these lights in a laboratory. However, Berger-Schunn (1994) stated that because the spectral power distribution of an illuminant is generally only used for calculation, it does not have to exist as a light source. Such is the case for classifying colored bar codes.

## Object

The last component necessary to measure color is the object itself. The CIE determined that if the observer and illuminant were constant, an object's color could be represented in a two-dimensional color space, called the chromaticity diagram (see Figure 2) widely described in the literature (Clulow, 1972; Committee on Colorimetry, 1963; Hunt, 1987; Judd & Wyszecki, 1975; Wyszecki & Stiles, 1982). The spectral locus (the curved boundary) represents a specific wavelength – a color in its richest or purist form. The straight line at the lower right is called the purple line because it does not represent a unique wavelength. Rather, colors along the purple line are some combination of red and blue. Near the center of the diagram is a noticeable white region. At the center of the white region is a point whose coordinates represent the standard illuminant, or equivalently, the point where R, G, and B are mixed in equal quantities to form white light.

An object's color can be located within the chromaticity diagram once its spectral distribution is determined and chromaticity coordinates are calculated. When using commercially available colors, like Pantone (1996) colors, often the chromaticity coordinates are already calculated. If chromaticity coordinates are unknown, they can be calculated using the data from a spectrophotometer.

## Calculating Chromaticity Coordinates

When viewing the chromaticity diagram, all visible colors fall within the region bounded by the curved spectral locus and the purple line (Figure 2). Furthermore, all colors have a unique combination of tristimulus (X,Y,Z) values that describe them. The tristimulus values of an object, whose color we wish to measure, are calculated using three variables: a CIE standard illuminant, a CIE standard observer, and the reflectance values of the object over the visible spectrum (Judd & Wyszecki, 1975). Both the CIE standard observer and illuminant values (see Tables 1 and 2, respectively) are expressed over the visible spectrum and are published in most texts on colorimetry (Kaufman & Haynes, 1981; Wyszecki & Stiles, 1982) as well as the published CIE standard.

Kaufman and Haynes (1981) related that once the spectral reflectance values of the specimen (spectrophotometer data) are known, the tristimulus values are calculated using the following relations:

$$X = k \sum_{\lambda=380}^{\lambda=780} S_\lambda \rho_\lambda \bar{x}_\lambda$$

$$Y = k \sum_{\lambda=380}^{\lambda=780} S_\lambda \rho_\lambda \bar{y}_\lambda$$

$$Z = k \sum_{\lambda=380}^{\lambda=780} S_\lambda \rho_\lambda \bar{z}_\lambda$$

where:

$S_\lambda$ is the spectral distribution of the standard illuminant,

$\rho_\lambda$ is the spectral reflectance of the specimen,

$\bar{x}_\lambda, \bar{y}_\lambda$, and $\bar{z}_\lambda$ are the spectral tristimulus values of the standard observer,

$k = \frac{100}{\sum S_\lambda \bar{y}_\lambda}$ is a normalizing factor,

***Figure 1. Principle of Trichromatic Color Matching by Additive Mixing of Lights. Red, Green, and Blue are lights whose intensities can be adjusted; Color is the light whose color is to be matched (adapted from Hunt, 1987).***

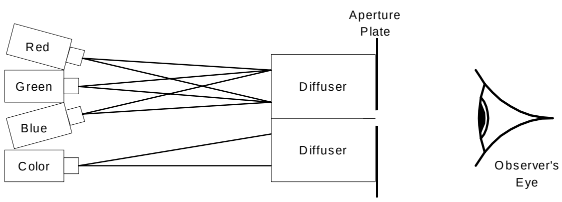
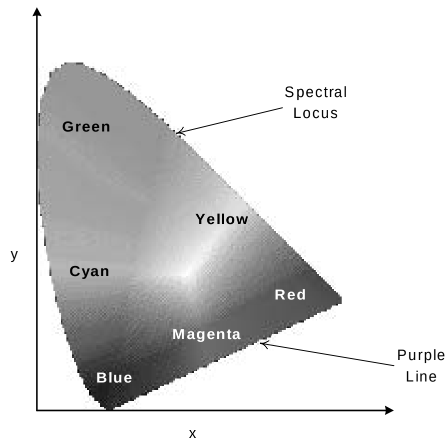



***Figure 2. The CIE Chromaticity Diagram. Colors are represented by coordinates (x, y) within the region bounded by the spectral locus and the purple line (adapted from Chamberlin & Chamberlin, 1980).***



λ represents wavelengths over the visible spectrum.

Given a specimen's tristimulus values, X, Y, and Z, the chromaticity coordinates for that specimen, x, y, and z may be calculated using the following equations:

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

$$z = \frac{Z}{X + Y + Z}$$

The above equations imply $x + y + z = 1$ and the coordinates are simple proportions of X, Y, and Z that represent the tristimulus values of a particular color. By convention, chromaticity is expressed as *x* and *y*, which together correspond to dominant wavelength and purity (Judd & Wyszecki, 1975). The third characteristic required to adequately define a color is brightness or luminance.

Billmeyer (1981) explained that in the CIE system, Y is known as the luminance factor and represents the perceived lightness of an object. The value Y = 100 is assigned to a perfectly white object that reflects 100% at all wavelengths and is the maximum value Y can have. Chromaticity coordinate z is not used to describe color. Knowing Yxy is sufficient to describe a color because these values provide enough information to calculate z, and hence, X, Y, and Z – the tristimulus description of a unique color.

## *Classifying Bar Code Colors*

In order to objectively assign a hue (color name) to a bar code, the CIE chromaticity diagram can be divided into conveniently sized regions (see Figure 3). First, determine the size interval and determine the boundaries of those intervals over the visible spectrum (380 nm to 780nm) and determine the corresponding chromaticity coordinates

***Table 1. Standard Observer Tristimulus Values (Kaufman & Haynes, 1981).***

| Wave-length (nm) | $\bar{x}_\lambda$ | $\bar{y}_\lambda$ | $\bar{z}_\lambda$ |
|---|---|---|---|
| 380 | 0.0002 | 0.0000 | 0.0007 |
| 390 | 0.0024 | 0.0003 | 0.0105 |
| 400 | 0.0191 | 0.0020 | 0.0860 |
| 410 | 0.0847 | 0.0088 | 0.3894 |
| 420 | 0.2045 | 0.0214 | 0.9725 |
| 430 | 0.3147 | 0.0387 | 1.5535 |
| 440 | 0.3837 | 0.0621 | 1.9673 |
| 450 | 0.3707 | 0.0895 | 1.9948 |
| 460 | 0.3023 | 0.1282 | 1.7454 |
| 470 | 0.1956 | 0.1852 | 1.3176 |
| 480 | 0.0805 | 0.2536 | 0.7721 |
| 490 | 0.0162 | 0.3391 | 0.4153 |
| 500 | 0.0038 | 0.4608 | 0.2185 |
| 510 | 0.0375 | 0.6067 | 0.1120 |
| 520 | 0.1177 | 0.7618 | 0.0607 |
| 530 | 0.2365 | 0.8752 | 0.0305 |
| 540 | 0.3768 | 0.9620 | 0.0137 |
| 550 | 0.5298 | 0.9918 | 0.0040 |
| 560 | 0.7052 | 0.9973 | 0.0000 |
| 570 | 0.8787 | 0.9556 | 0.0000 |
| 580 | 1.0142 | 0.8689 | 0.0000 |
| 590 | 1.1185 | 0.7774 | 0.0000 |
| 600 | 1.1240 | 0.6583 | 0.0000 |
| 610 | 1.0305 | 0.5280 | 0.0000 |
| 620 | 0.8563 | 0.3981 | 0.0000 |
| 630 | 0.6475 | 0.2835 | 0.0000 |
| 640 | 0.4316 | 0.1798 | 0.0000 |
| 650 | 0.2683 | 0.1076 | 0.0000 |
| 660 | 0.1526 | 0.0603— | 0.0000 |
| 670 | 0.0813 | 0.0318 | 0.0000 |
| 680 | 0.0409 | 0.0159 | 0.0000 |
| 690 | 0.0199 | 0.0077 | 0.0000 |
| 700 | 0.0096 | 0.0037 | 0.0000 |
| 710 | 0.0046 | 0.0018 | 0.0000 |
| 720 | 0.0022 | 0.0008 | 0.0000 |
| 730 | 0.0010 | 0.0004 | 0.0000 |
| 740 | 0.0005 | 0.0002 | 0.0000 |
| 750 | 0.0003 | 0.0001 | 0.0000 |
| 760 | 0.0001 | 0.0000 | 0.0000 |
| 770 | 0.0001 | 0.0000 | 0.0000 |
| 780 | 0.0000 | 0.0000 | 0.0000 |

(see Kaufman & Haynes, 1981). Next, calculate the chromaticity coordinates ($x$, $y$) for the bar code (bars and spaces), if not readily available. Finally, transform the interval boundaries and bar/space chromaticity coordinates to polar coordinates ($r$,$\theta$). Unlike ($x$, $y$) coordinates which represent a point in a two-dimensional Cartesian plane, polar coordinates represent the same point as the distance from the origin, $r$, and the angle measure, $q$, about the origin with respect to the $x$-axis. The transformation is based on standard illuminant $D_{65}$ as the origin, instead of (0, 0). Table 1 shows that the chromaticity coordinates for $D_{65}$ are $(x_{D_{65}}, y_{D_{65}})$ = (0.3138,0.3309).

For example, the following two steps illustrate how the Pantone Green specimen's chromaticity coordinates, $(x_g, y_g)$ = (0.1872,0.4514), were converted to polar coordinates:

Convert $(x_g, y_g)$ to $(x'_g, y'_g)$ such that standard illuminant $D_{65}$ is the new origin.

$$\begin{aligned}(x'_g, y'_g) &= (x_g - x_{D_{65}}, y_g - y_{D_{65}}) \\ &= (0.1872 - 0.3138, 0.4514 - 0.3309) \\ &= (-0.1266, 0.1205)\end{aligned}$$

Convert $(x'_g, y'_g)$ to $(r_g, \theta_g)$, the Pantone Green specimen's polar coordinates.

$$\begin{aligned}r_g &= \sqrt{x_g'^2 + y_g'^2} \\ &= \sqrt{(-0.1266)^2 + (0.1205)^2} \\ &= \sqrt{0.01603 + 0.01452} \\ r_g &= 0.1748\end{aligned}$$

$$\begin{aligned}\theta_g &= \arctan\left(\frac{y'_g}{x'_g}\right) \\ &= \arctan\left(\frac{0.1205}{-0.1266}\right) \\ \theta_g &\approx 136^\circ\end{aligned}$$

Once $\theta$ is determined from $D_{65}$ to the spectral locus on the chromaticity diagram for each of the chosen wavelength boundaries, the regions are

***Table 2 – CIE Spectral Power Distributions of Standard Illuminant $D_{65}$ (Kaufman & Haynes, 1981).***

| Wavelength l(nm) | $S_\lambda \bar{x}_\lambda$ | $S_\lambda \bar{y}_\lambda$ | $S_\lambda \bar{z}_\lambda$ |
|---|---|---|---|
| 380 | 0.001 | 0.000 | 0.003 |
| 390 | 0.011 | 0.001 | 0.049 |
| 400 | 0.136 | 0.014 | 0.613 |
| 410 | 0.667 | 0.069 | 3.066 |
| 420 | 1.644 | 0.172 | 7.820 |
| 430 | 2.348 | 0.289 | 11.589 |
| 440 | 3.463 | 0.560 | 17.755 |
| 450 | 3.733 | 0.901 | 20.088 |
| 460 | 3.065 | 1.300 | 17.697 |
| 470 | 1.934 | 1.831 | 13.025 |
| 480 | 0.803 | 2.530 | 7.703 |
| 490 | 0.151 | 3.176 | 3.889 |
| 500 | 0.036 | 4.337 | 2.056 |
| 510 | 0.348 | 5.629 | 1.040 |
| 520 | 1.062 | 6.870 | 0.548 |
| 530 | 2.192 | 8.112 | 0.282 |
| 540 | 3.385 | 8.644 | 0.123 |
| 550 | 4.744 | 8.881 | 0.036 |
| 560 | 6.069 | 8.583 | 0.000 |
| 570 | 7.285 | 7.922 | 0.000 |
| 580 | 8.361 | 7.163 | 0.000 |
| 590 | 8.537 | 5.934 | 0.000 |
| 600 | 8.707 | 5.100 | 0.000 |
| 610 | 7.946 | 4.071 | 0.000 |
| 620 | 6.463 | 3.004 | 0.000 |
| 630 | 4.641 | 2.032 | 0.000 |
| 640 | 3.109 | 1.295 | 0.000 |
| 650 | 1.848 | 0.741 | 0.000 |
| 660 | 1.053 | 0.416 | 0.000 |
| 670 | 0.575 | 0.225 | 0.000 |
| 680 | 0.275 | 0.107 | 0.000 |
| 690 | 0.120 | 0.046 | 0.000 |
| 700 | 0.059 | 0.023 | 0.000 |
| 710 | 0.029 | 0.011 | 0.000 |
| 720 | 0.012 | 0.004 | 0.000 |
| 730 | 0.006 | 0.002 | 0.000 |
| 740 | 0.003 | 0.001 | 0.000 |
| 750 | 0.001 | 0.001 | 0.000 |
| 760 | 0.001 | 0.000 | 0.000 |
| 770 | 0.000 | 0.000 | 0.000 |
| Sums (X, Y, Z) | 94.825 | 100.000 | 107.381 |
| Chromaticity (x, y, z) | 0.3138 | 0.3309 | 0.3553 |

defined. A bar code's colors (bar or space), whose polar coordinates fall within a specific color region, is assigned that hue. Given a population of colors, like Pantone (1998), plotted in the chromaticity diagram, define regions sufficiently small such that variation within the region is minimized. Calculate mean reflectance for the population colors that fall within each region. After we know from what regions a particular bar or space is located, symbol contrast can be closely estimated by subtracting the bar-region mean from the space-region mean. This estimate of symbol contrast will indicate how well the bar-space color combination will perform as a printed bar code symbol.

## Discussion

This research proposes a standard method of objectively classifying bar codes printed on colored substrates so that scanning success can be predicted. Current practices follow rule-of-thumb guidelines or the subjective evaluation of the package designer, if at all.

The primary contribution of the method proposed here removes the subjectivity of classifying colors, especially when hues are a mix between one that is generally acceptable (i.e., yellow) and one that is poor (i.e., green). Using the CIE chromaticity diagram to determine a hue's chromaticity in two-dimensional space eliminates the variability between two or more individual's perceptual classifications of the same color. A standard method is needed to prevent unsuitable (unreadable) bar-space color combinations from going to press.

## Conclusion

To date, no standardized method exists to objectively classify a bar code's bar-space color combination. The proposed method provides a theoretical, yet practical, model that will help determine if a bar code will scan successfully prior to printing. The method serves to substantiate existing rule-of-thumb guidelines. Furthermore, the method allows for classifying colors in hue regions that are sufficiently small – small enough to differentiate between two hues that would otherwise appear to be the same color to individuals viewing them.

Proposing a method to classify colored bar codes to predict scanning success, suggests further research to answer the following questions:

1) What bar code colors are generally preferred for bars? For spaces?
2) Is there an ideal bar-space color combination to optimize scanning success?
3) Do the wavelengths of laser light generally used in bar code scanners significantly affect scanning success of colored bar codes?
4) What effect, if any, does the saturation level (white component) of a hue have on bar code scanning success?

Answers to these questions will help provide a bar code with a readable combination of bar-space colors before the symbol is actually printed. Furthermore, addressing these questions will fill a noticeable void in the bar code print quality body of knowledge.

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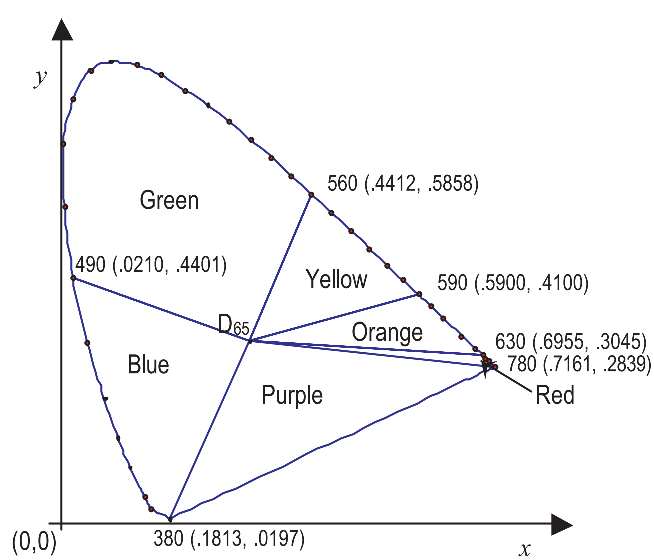
***Figure 3. The CIE 1964 Chromaticity Diagram with Six Color Regions Defined (Wavelength Followed by Chromaticity Coordinates).***



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