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An analysis of the consistency of brand color reproduction in print packaging and magazine advertising

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An Analysis of the Consistency of Brand Color Reproduction in Print Packaging and Magazine Advertising

By

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Abstract

Brand color is one way to represent the identity of the corporation and for the company to advertise itself. The purpose of brand color is to make customers perceive the color, recognize the brand, and ultimately buy products manufactured by the corporation. However, it is not easy to produce the same color through different print media applications because of different processes of color reproduction technology. In the print industry, corporations have controlled brand color tolerance to insure its consistency. However, there is some question as to how the print industry actually performs in maintaining this tolerance through reproduction.

The goal of this research is to find out what variability exists in commercial packaging and magazine advertising. CIE LAB (color space proposed by the CIE to attempt a perceptually uniform color space) was used to measure the difference in both media.

For the methodology, brand colors based on the hue circle were selected for sampling and measurement. Seven colors were chosen for commercial packaging: Kodak yellow, Fuji green, Coca Cola red, Sunkist orange, Chips Ahoy cyan, Pepsi deep blue, and Alpha Bits cereal magenta. Two samples, Kodak yellow and Fuji green, were chosen for examples of magazine colors. The instrument, an X-Rite spectrophotometer, model 528, 500 series, was calibrated in D50/2 for the measurement. The value of each color was acquired by the mean of three measurements. The samples were measured from ten Wegman's

grocery stores near the Rochester area and the RIT bookstore over a period of five months.

For the magazine advertisement, only two colors, Kodak yellow and Fuji green, were selected, because the advertisement of the other brand colors were not readily found in magazines. The magazines in the sample were photo - related magazines and published in the past five years. The measurement period was from May 13 to September 20, 2003. Three different methods are used for the analysis of results: a*b* slice plot with constant L value, Lab axis plot from Dr. Granger, and the CRF (Cumulative Relative Frequency) curves.

As a result, each brand color has different performance in terms of color matching. For commercial packages, Sunkist orange has the smallest color difference, whereas Kodak yellow has the largest color difference. Post Alpha Bits magenta and Chip's Ahoy cyan were close to Sunkist orange, which means that they have a relatively small color difference. Pepsi's deep blue was close to Kodak yellow, which means Pepsi has a relatively large color difference. For the magazine advertising, the variation is much greater than that of the packages measured. According to the findings, each brand color for commercial packaging shows different performance in terms of color matching. The color match should be $\Delta E < 2$. From the aspect of the 90th percentile of samples for each brand color, none of samples is $\Delta E < 2$. Assuming the expectation of the print service providers is that the sample for brand color should fall within acceptable tolerances, alternative hypothesis (Ha) is accepted. With respect to the measurement of the accurate

reproduction of brand colors, the actual performance of print services providers shows variation in color reproduction that exceeds acceptable tolerances for color matching.

For the samples of solid brand color, seven brand colors are selected based on the hue circle. Samples of each brand color show the different variation in terms of ΔE and move toward different CIE LAB axes. This result shows that controlling the variation of brand color should consider the nature of the variations.

From the aspect of color matching, the variation of brand color for magazine advertisement is much greater than that for film packages. This is primarily due to the wider range of substrates and the print process technology and process color application inherent in publication printing.

Thus, it is also concluded that the expectation of the companies for specifying color should be different for each type of application.

Chapter 1

Introduction

1.1 Background

A brand is a sign of identification, the label that differentiates the product from its competitors. It can also act as a type of shorthand encapsulating the key features of the product, such as its image, use and price, in an easily recognized and remembered form[1] (p.33). Brand color is one way to represent the identity of the corporation and for a company to advertise itself. Color packaging plays a part in the image communication of the product [2] (p.16). The purpose of brand color is to make customers perceive the color, recognize the brand, and ultimately buy products manufactured by the corporation. For this purpose, brand color should make customers perceive the color consistently. However, it is not easy to produce the same color consistently through many different print processes and applications. In spite of these challenges, industry color tolerance should represent color variations that people will accept.

Color tolerance can be defined as the customer acceptable variation of a specific color. It can be critical (tight), semi-critical (moderate), or not-critical (wide). Color tolerance is important because it is the factor that determines whether a color is accepted or rejected, based on the appearance of the product [3]. The actual decision as to what color range is to be written into the contract as acceptable is not easy. Color tolerance can be stated in

terms of special color standards made up for one order, stated in terms of a collection of color chips or based upon measurement, either by direct colorimetry or by spectrophotometry and calculation[4] (p.343).

1.2 Problem Statement

Today it is not difficult to find brand color from various media. When people buy product packages, read an advertisement in a magazine, or see the color on a computer screen, there are various ways to meet brand color.

In the print industry, corporations have controlled brand color tolerance to make sure the consistency of color meets some standard. However, there is a question as to how the actual performance of the print industry compares with the tolerance standards of the print buyer and print consumer.

1.3 Research Objectives

The goal of this research is to find out what variability exists in commercial packaging, and magazine advertising. For this purpose, CIE LAB (color space proposed by the CIE to attempt a perceptually uniform color space) will be used to measure the difference in both brand color media. The resulting differences will be plotted in a standard statistical control chart. From this, the variability of specified brand color will be determined and compared to standard industry practice.

Endnotes for Chapter 1

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Chapter 2

Theoretical Basis of the Study

2.1 Color

When it comes to defining color, there might be several definitions, but the one I will take for this thesis is that color is a property of objects, color is a property of light, and color is what perceived by the observer [1] (p.4). According to Berns (2000), color is what we see as the result of the physical modification of light by a colorant as detected by the human eye and interpreted in the brain[2] (p.1). Color is an event that occurs among three participants: a light source, an object, and an observer. If any of these three things changes, the color event is different -- we see a different color[1] (p.5).

2.2 Perceiving Color

Light entering the eye is imaged onto the back of the eyeball, the retina, where light is absorbed. A portion of the incident light generates a signal that is eventually interpreted by the brain. There are two classes of receptors, rods and cones. Rods detect very small amounts of light. As the amount of light increases, the rods become desensitized and cease sending signals to the brain. Cones are the color receptors. Stimuli that cause different colors have different cone signals[2] (p.13). There are three cone types, L, M, and

S, each with unique spectral and spatial properties. The cones combine to form opponent signals: black–white, red–green, and yellow–blue. The three opponent channels have different spatial resolution. By matching cone responses, it is possible for stimuli to match that do not have identical physical properties. These metameric stimuli are the basis for color reproduction and for matching materials using different colorants.

2.3 CIE Color Systems: CIE XYZ and CIE L*a*b*

In 1931, the *CIE* (International Commission on Illumination) established standards for color space that represents the color perception of human vision. The basic CIE color space is CIE XYZ. The color matching functions are the values of each light primary – red, green, and blue – that must be present in order for the average human visual system to perceive all colors [7](p14-15). To define or describe a certain color such as "Kodak Yellow", the tristimulus values, X, Y, Z of the color are necessary. XYZ defines the color perceived. The tristimulus variables can be thought of as a three-dimensional space. By performing two sequential projections, a two-dimensional map of color called the chromaticity diagram is obtained. Thus, color, as described in the CIE system, can be plotted on a chromaticity diagram. However, when matching two colors, the CIE chromaticity diagram can identify whether two colors have the same chromaticity. Two colors may have the same chromaticity and shall not match if they are at different illuminant levels. The CIE chromaticity system does not describe a visual space. Thus, color scientists and engineers have developed and continue to develop new color spaces with the goal of providing uniform visual spacing and correlation with color perception[2].

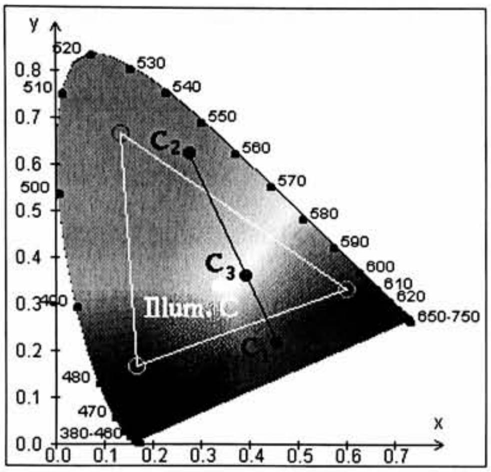

Figure 1. CIE xy Chromaticity Diagram[3]

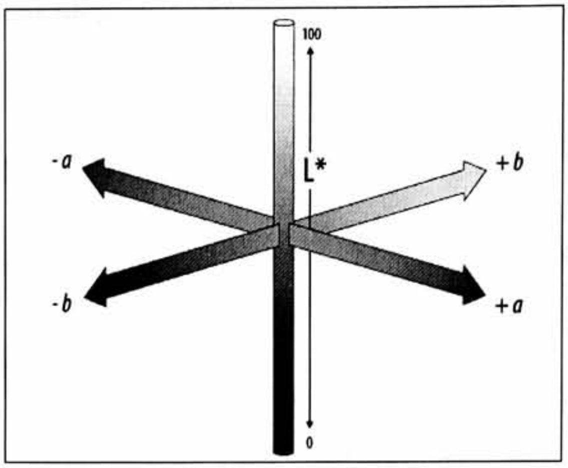

Figure 2. LAB Color Space[4]

A color difference space is three-dimensional with approximately uniform visual spacing in terms of color difference judgment. It is a transformation of the tristimulus space in which the transformation parameters are optimized using a dataset of visual judgment. The two current color difference systems are CIE L*a*b* and CIE L* u* v*[3].

In 1976, the CIE decided to recommend these two color spaces for practical use. CIE L* u* v* is used only in special cases when additives mixtures are to be judged. CIE LAB is an opponent color system based on the earlier (1942) system of Richard Hunter called L, a, b. Color opponent systems correlate with discoveries in the mid-1960s that somewhere between the optical nerve and the brain, retinal color stimuli are translated into distinctions between light and dark, red and green, and blue and yellow. The CIE LAB color opponent axes are: L*, a*, and b*.

In 1976, the CIE improved performance relative to tristimulus value to achieve the goal of visual uniformity. The central vertical axis represents lightness (signified as L*) whose values run from 0 (black) to 100 (white). On the a* axis, positive values indicate amounts

of red while negative values indicate amounts of green. On the b*' axis, yellow is positive and blue is negative[4].

2.3.1 Equations for CIE LAB Color Space

The CIE LAB color space involves nonlinear functions of the tristimulus values (X, Y, Z) and the reference substrate (X_n, Y_n, Z_n) that usually correspond to those of the standard illuminant with Y_n equal to 100 [16].

The mathematics involved in this color space can be expressed as follows.

$L^* = 116\,[f\,(Y/Y_n) - 16/116]$

$a^* = 500\,[f\,(X/X_n) - f\,(Y/Y_n)]$

$b^* = 200\,[f\,(X/X_n)^{1/3} - f\,(Z/Z_n)]$

where $f\,(Y/Y_n) = (Y/Y_n)^{1/3}$ for Y/Y_n greater than 0.008856, and $f\,(Y/Y_n) = 7.787\,(Y/Y_n) + 16/116$ for Y/Y_n less than or equal to 0.008856; $f\,(X/X_n)$ and $f\,(Z/Z_n)$ are similarly defined (p. 69)[2].

For these calculations, the value for D50, 2 degree observer, and the white point with $X_n = 96.422$, $Y_n = 100.000$, $Z_n = 82.521$ shall be used, as stated in the ANSI CGATS.5[17].

2.4 Color Difference

Historically, a number of color spaces and color-difference equations have developed to produce a perceptually uniform color space. In nearly every case, there is a poor correlation between the dataset of visual judgments and the Euclidean distances in a given color space. There is a need to further optimize these equations. There are three reasons cited for the inability of color scientists and engineers to solve this problem: large observer uncertainty, the many factors affecting visual judgments, and the likelihood that the color space is non-Euclidian[2]. CIE LAB space, which is widely used, is a poor uniform color space, at least where small color difference are concerned (see Figure 4). Some clear trends in Figure 3 can be found: ellipses close to neutral colors are the smallest; most ellipses point towards the neutral point except the blue region.

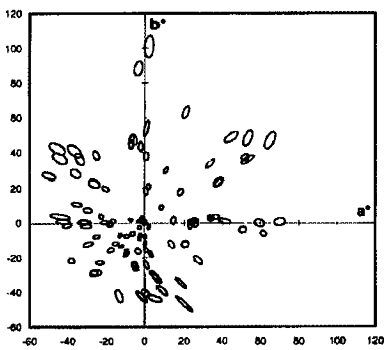

Figure 3. Color Discrimination Ellipses[5]

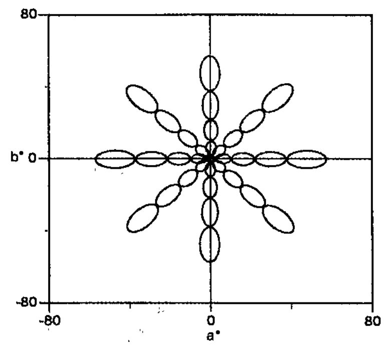

Figure 4. Uniform Color Equation[2]

2.4.1 Color Difference ΔE_{ab}

The distance between two samples ΔE in a visual uniform color space corresponds to the color difference between two samples. The formula of ΔE used in CIE LAB 1976 is the Adams and Nickerson formula: $\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$

where the particular differences are:

in lightness $\Delta L^* = L^*_{sample} - L^*_{reference}$

in a* coordinate $\Delta a^* = a^*_{sample} - a^*_{reference}$

in b* coordinate $\Delta b^* = b^*_{sample} - b^*_{reference}$

The color differences could be easily calculated using this formula.

The interpretation of color difference ΔE^*_{ab} is the difference between the L* a*b* positions of the sample color and the reference color[6]. Based on Chung's[18], Beckmenn 's and collaborator's[19] work, the ΔE^*_{ab} yardstick may be stated as shown in Table 1.

<table>
<tr><th>ΔE* ab</th><th>Match</th><th>Evaluation</th></tr>
<tr><td>< 0.2</td><td rowspan="2">Excellent</td><td>Invisible</td></tr>
<tr><td>0.2 to 1.0</td><td>Very low</td></tr>
<tr><td>1.0 to 2.0</td><td>Good</td><td>Low</td></tr>
<tr><td>3.0 to 4.0</td><td>Fair</td><td rowspan="2">Medium</td></tr>
<tr><td>4.0 to 6.0</td><td>Poor</td></tr>
<tr><td>> 6.0</td><td>No longer
Considered a match</td><td>High</td></tr>
</table>

Table 1. ΔE^*_{ab} Yardstick [6] (P.11)

2.5 ΔE and Its Distribution

ΔE is the total color difference between a reference and a sample. It only reflects the magnitude of the color difference. It does not identify how the two colors differ. Evaluating ΔE^*_{ab} between image elements has two characteristics: central tendency and range. The central tendency includes the average ΔE^*_{ab}, the median, and the mode. The range is given by $\Delta E^*_{ab,\ max}$ and $\Delta E^*_{ab,\ min}$ values. An average of all the color differences, evaluated over all the colors in a color target, may introduce an incorrectly weighted color variation when doing color matching between a reference and a sample.

For three variables x,y,z, the trivariate distribution for (x,y,z), in which these components are independent normal variances with mean zero and common variance σ^2, might be called a spherical normal distribution. The distance from the origin out to the point (x, y, z) is a random variable.

To evaluate color difference, the color difference of individual colors should be assumed to have a Maxwell distribution as explained below.

$$R = (x^2 + y^2 + z^2)^{1/2}$$

The result is defining the probability density function known as the Maxwell distribution[13]. CIE LAB uses coordinates (L*, a*, and b*) to establish the position of a color in the Euclidean space. The ΔE_{ab} also forms a Maxwell distribution, because $\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. The sum of the squared difference between the variables L*, a* and b* should be assumed to be a Maxwell distribution, where we assume that ΔL*, Δa* and Δb* are Gaussian, distributed with 0 mean.

Once we measure a sufficient number of samples, the mean of color measurements can serve as the reference. ΔEs between the color measurements and the mean show the ΔE distribution.

According to Dolezlaket(1997), mean and standard deviation of ΔE are not the best descriptor of statistics, because press-induced ΔE distribution is asymmetrical[9]. For the variability in press characterization, Bartel and Fisch (1999) adopted the use of a CumSum % graphing procedure referred to as the Donnelley initiatives[15].

Chung (2001) showed that Cumulative Relative Frequency (CRF) curves have advantages for the quantitative analysis of color differences[8]. CRF (Culmulative Relative Frequency) is the combination of relative frequency and culmulative frequency.

For the comparison of the frequency of different numbers of observations, it is useful to plot relative frequency (p.17) [14]. For finding the number of items in a lot which are smaller than, or greater than, a specified value, a plot of cumulative frequency is best displayed (p.29) [14]. From the Discussion section on Chung's presentation for Color Perception and Analysis in 2004, CRF curves are used to differentiate performance of color matching in Figure 5.

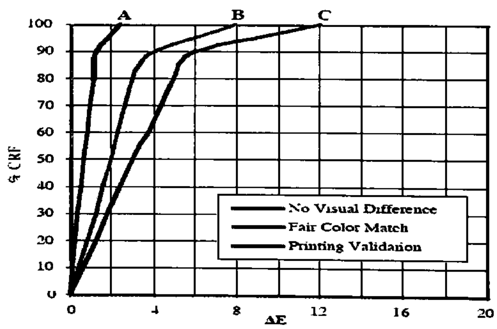

Figure 5. The Use of CRF Curves[20]

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Chapter 3

Review of the Literature in the Field

Brand power is a quality possessed by only the strongest international brands. A power brand is characterized by the distinctive nature of its brand personality, by appeal and relevance of image, by the consistency of its brand communication, by the integrity of its identity[1].

Brand identity is not necessarily just a name. There are numerous other means of creating brand identity and brand memorability. Many brands and their products can be identified instantly by their visual cues without the consumer's even reading their brand name: the yellow color of Kodak film packages, the silhouettes of Perrier, and Coca-Cola bottles, etc[2].

The consistent use of color as a means of creating brand image or brand awareness has received a good deal of attention. The use of colors is widely regarded as an essential part of a marketing plan; however; color alone will not create a company image nor will it create brand awareness. There must be an easily recognizable symbol or shape as well[3].

Color is the not only factor that helps a package to do a selling job but it is an important part of the whole. People do not buy a package for itself but for what it contains. In choosing between competitive packs they are motivated by factors that are very often at a subconscious level. They rarely deliberate over a package, but are attracted to it and buy it; this is why color is so important – it often provides the sale impulse. Perception deals with why the customer sees as he does and how he senses form, shape, and color. It is psychological in nature rather than mechanical. All three must be considered together, but color is primary in human perception[3].

Judd and Wyszecki describe the psychological aspect from the customer's angle to predict what the average customer will see. The customer perceives color as belonging to the merchandise or to the package; that is, color, for the ultimate consumer, nearly always means object color. Each brand triggers a memory of a color or a range of colors that is acceptable. The essential part of the judgment is the character and the amount of difference between the actual color perceived and the mental standard to which it must conform[4].

There is a question on how to predict what the average customer will see. For this, it is necessary to find the method for predicting whether one specimen color matches another. In applying the CIE method, the manufacturer needs the spectral distribution of radiant flux emitted by the light source that illuminates his specimens and three weight functions in averaging the spectral reflectance of each specimen. These weighting functions are

called color matching functions and characterize the color matching properties of an average observer with normal color vision [4].

Color tolerance can be defined as the acceptable variation of a specific color that a customer will accept. It can be critical (tight), semi-critical (moderate), or not-critical (wide). Color tolerance is important because it is the factor that determines whether a color is accepted or rejected, based on the appearance of the final product[6].

The actual decision as to what color range is to be written into the contract as acceptable is not easy. Color tolerance can be stated in terms of special color standards made up for one order or they may be stated in terms of a collection of color chips or they may be based upon measurement, either by direct colorimetry or by spectrophotometry and calculation[4] .

In 2003, GATF offered an accurate method of determining tolerance for an acceptable color match. This test is called the Pilot Color Tolerance Exercise Kit. Windows away from direct sunlight and 5000K are required for proper viewing conditions. Basically it compares a person's visual perception of an acceptable color match with a known, numeric standard to determine color difference (called Delta E). Using this exercise, a manager can determine a company-wide standard for color tolerance. The data can also indicate whether the quality and repeatability of color measurement devices, scanners, monitors, and output devices fall within acceptable tolerance standards[5].

The Visual Color Systems Company also provides a color tolerance test. First they select a primary target color, and then they develop a realistic color range designed exclusively for each application[7].

Endnotes for Chapter 3

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Chapter 4

The Hypotheses

Ho: (null hypothesis)

With respect to the measurement of the accurate reproduction of brand colors, the actual performance of print services providers shows variation in color reproduction that does not exceed acceptable tolerances for color matching

Ha: (alternative hypothesis)

With respect to the measurement of the accurate reproduction of brand colors, the actual performance of print services providers shows variation in color reproduction that exceeds acceptable tolerances for color matching.

Chapter 5

Methodology

5.1 Sampling

The first procedure is to decide on the sampling. Considering statistical aspects of this research, sampling methodology was discussed with Dr. Granger and the selection of brand colors was based on the hue circle.

The actual sample set was randomly selected and was acquired at the bookstore at RIT, the Wegman's grocery stores near Rochester and at the RIT library. The measurement was done under consistent conditions with the same instrument.

5.1.1 Selection of Samples

For selecting brand color, seven colors based on the hue circle were chosen.

Hue is that attribute of a color by which we distinguish red from green, blue from yellow, and so on. There is a natural order of hues: red, yellow, green, blue, purple. One can mix paints of adjacent colors in this series to obtain a continuous variation from one color to the other.[1] The hue circle is a circular chart illustrating all the colors of the visible spectrum in sequence order by wavelength in Figure 6. Complementary colors are opposite each other on the hue circle (p.163)[2]. From the hue circle, yellow, green, cyan, deep blue, magenta, orange, and red were selected for this study.

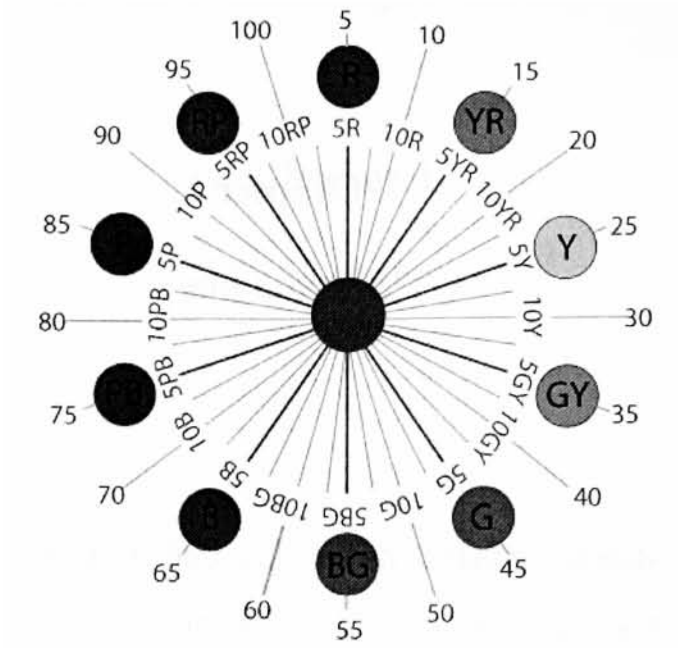

Figure 6. Hue Circle

After selecting colors, package products from the grocery stores were investigated to make sure that some products had these colors. Thus, the seven samples for brand color from packages are as follows: Kodak yellow, Fuji green, Coca Cola red, Sunkist orange, Chip's Ahoy cyan, Pepsi deep blue, Alpha Bits cereal magenta. Two samples, Kodak yellow and Fuji green, were chosen for examples of magazine colors.

5.2 Measurement

The second procedure was to measure the CIE LAB value of each sample. For the instrument, an X-Rite spectrophotometer, model 528, 500 series was calibrated in D50/2. The number of samples for each brand is shown in Table 2.

Color	Brand Name	Packages	Magazine
Yellow	Kodak	100	60
Green	Fuji	90	59
Red	Coca Cola	100	--
Orange	Sunkist	100	--
Cyan	Chip's Ahoy	100	--
Deep blue	Pepsi	100	--
Magenta	Alpha Bits Cereal	100	--

Table 2. The Number of Samples for Each Brand Color

The value of each color was acquired by the mean of three measurements. The measurement period was from May 13 to September 20, 2003.

For commercial packaging, the samples were measured from ten Wegman's grocery stores near the Rochester area and the RIT bookstore.

Samples of products were carbon type packages.

For the magazine advertisement, only two colors, Kodak yellow and Fuji green, were selected, because advertisements of other brand color were not readily found in the magazines. The magazines for sampling were photo-related magazines and published within the past five years. The samples were randomly selected. The list of samples for magazine is shown in Table 3.

Name of Magazine	Published Year
Photo Lab Management	1999
Photo Marketing	1999~2003
PEI	2003

Table 3. The List of Samples for Magazine Advertising

5.3 Analysis

To find out how brand color varies in terms of CIE LAB value, three different methods were used: Lab axis plot from Dr. Granger, a*b* slice plot with constant L* value, and the CRF (Cumulative Relative Frequency) curves.

First, the L*a*b* axis plot shows not only the data located by three axes, but also the data scattered about the mean. The center point is the average of the data. It indicates the reference value, and the plotted dot is the variation from the reference. The scale is from ΔE 0 to 10. It can compensate for the limitation of a*b* slice, which is constant L value.

Second, the a*b* slice plot with constant L* indicates the location brand color in the a*b* axes. It can give the general variation of each brand color, but it still has the limitation that L* values are constant.

Third, the CRF (Cumulative Relative Frequency) curve is used for the quantitative analysis of color difference. It is the combination of relative frequency and cumulative frequency from the chart. ΔE is in ascending orders on the x-axis, and the sum of the percent is ranked on the y-axis.

Endnotes for Chapter 5

1. *Hue Circle*. Retrieved December 12, 2003, from http://www.gretagmacbeth.com/Source/Solutions/munsell/index.asp#a2

2. Romano, F. J. & Romano, R, M, (Eds.).(1998). *The GATF Encyclopedia of Graphic Communication*. Sewickley, PA: GATF Press.

Chapter 6

The Results

6.1 Brand Color on Commercial Packaging

To achieve the goal of this research, the variability of specified brand color was determined and compared by measuring CIE LAB on commercial packaging. For the measurement, seven samples from packages were chosen: Kodak yellow, Fuji green, Coca Cola red, Sunkist orange, Chips Ahoy cyan, Pepsi Deep blue, Alpha Bits cereal magenta. Three different methods were used for analysis of the results: a*b* slice plot with constant L* value, L*a*b* axis plot from Dr. Granger, and the CRF (Cumulative Relative Frequency) curves.

6.1.1 Kodak Yellow

According to the sample data, the maximum, minimum, and average L*a*b* values acquired are shown in Table 3. The average value serves as the reference value to determine the variation. From Table 3, the variation for b* is the largest among three axes.

	L*	a*	b*
Min.	73.6	16.6	71.8
Max.	79.5	22.7	88.9
Ave.	77.2	20.1	81.6

Table 4. CIE LAB of Kodak Yellow in Commercial Packages

Figure 6 shows the L*a*b* variation of the samples from Kodak Yellow film packages independent of the L value. From Figure 7, all data are plotted around the aim point, which is the reference value. The variation along b* is much larger than a*. The b* axis shows the yellowness (a+) and blueness (a-), while the a* axis indicates the redness (b+) and greenness (b-). Kodak Yellow on film packages has more yellow and blue hue variation than it has red and green.

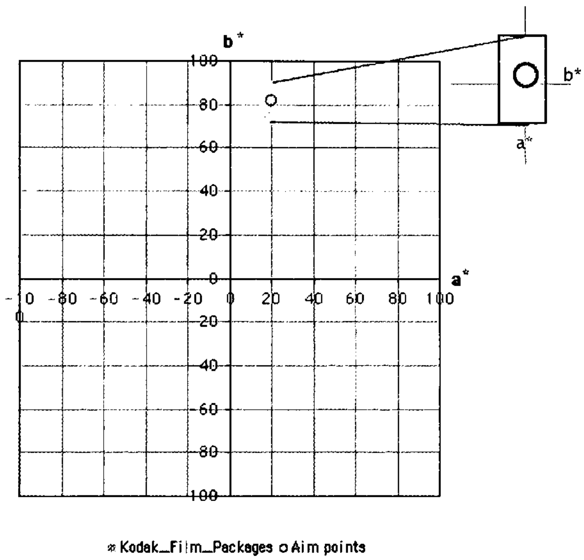

Figure 7. a* b* Diagram of Kodak Yellow in Commercial Packages

From the Lab axis in Figure 8, the center point, the average of the data, indicates the reference value, and the plotted dot is the variation from the reference. The scale is from ΔE 0 to 10. From Figure 7, the dotted line shows how the data are distributed in CIE LAB space. As shown in Figure 7, the dot along the b* axis is the most dispersed, and it is significantly scattered along L* axis. Based on this finding, Kodak Yellow on film packages shows the most variation in yellow and blue hue, and also indicates the

lightness difference. Also, the dot plotting is inclined to have clusters. From the methodology of sampling, this clumping of product differences is due to the product being manufactured in different batches.

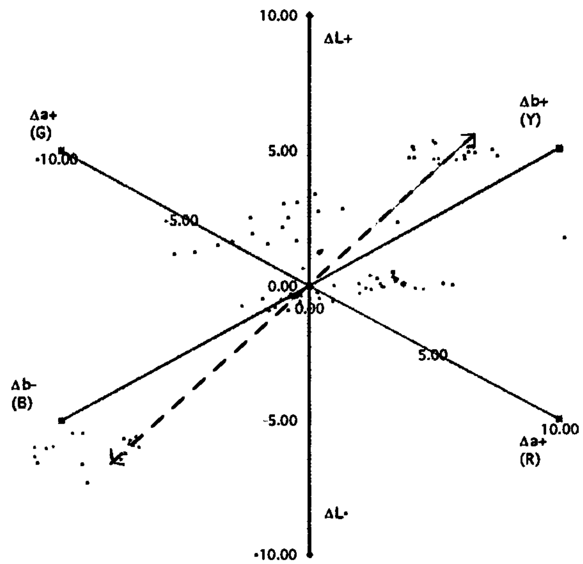

Figure 8. Three Dimensional Lab Plot of Kodak Yellow in Commercial Packages

The Cumulative Relative Frequency (CRF) shows the quantitative analysis of color differences. This curve shows a ΔE of 3.60 at the 50 percentile, 8.23 at the 90 percentile, and 10.45 at unity.

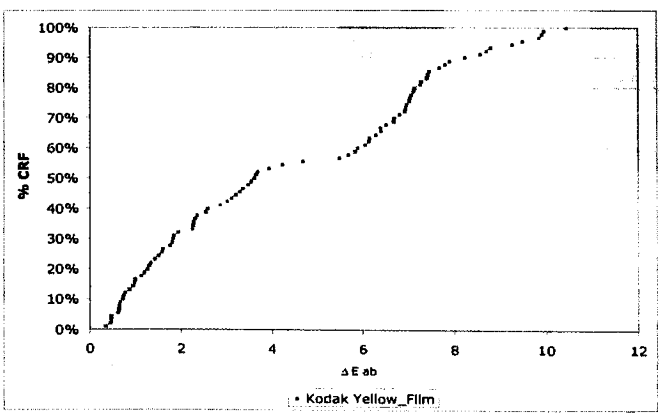

Figure 9. CRF Curves of Kodak Yellow in Commercial Packages

6.1.2 Fuji Green

For the Fuji Green film packages, the maximum, minimum, and average L*a*b* values are shown in Table 4. For the variation, both a* and b* are larger than L*.

	L*	a*	b*
Min.	49.6	-78.2	35.4
Max.	54.4	-69.6	43.0
Ave.	52.3	-74.9	38.8

Table 5. CIE LAB of Fuji Green in Commercial Packages

From Figure 10, all data are plotted around the aim point.

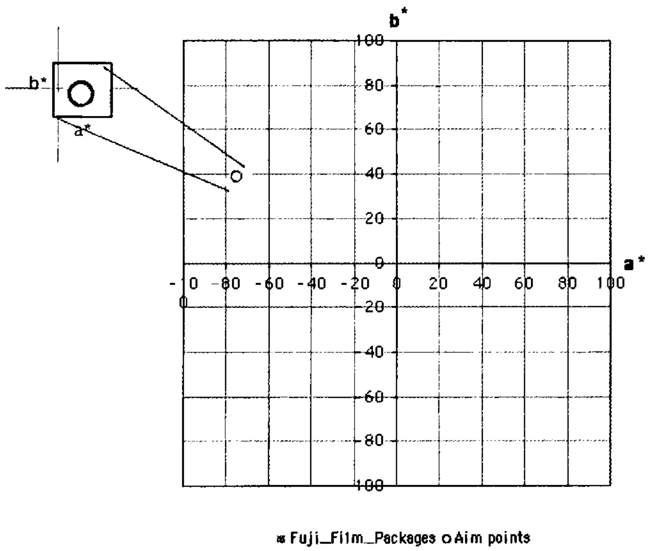

Figure 10. a* b* Diagram of Fuji Green in Commercial Packages

From Figure 11, the samples are apparently clustered, but the variation is within ΔE=5. Among three axes, the dot plotting is the most dispersed along the a* axis. This shows that the color dispersion of the Fuji Film Green was probably due to changes in saturation or inks. It is also shown that like Kodak, Fuji has a large variation of logo color.

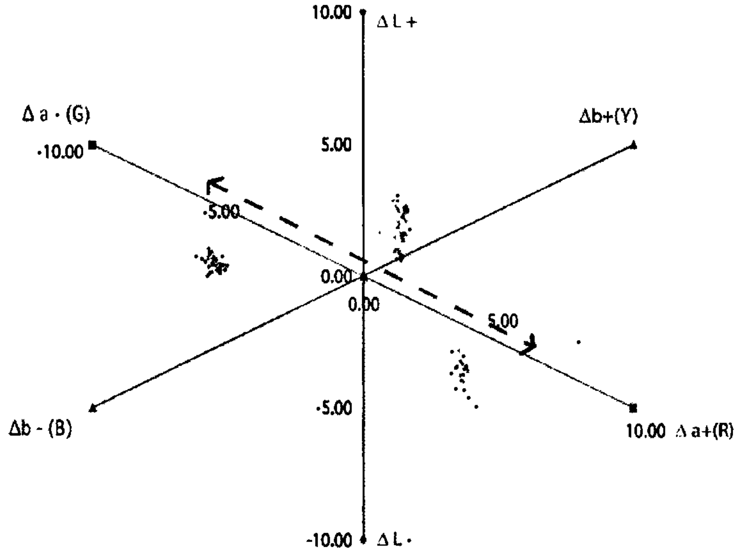

Figure 11. Three Dimensional Lab Plot of Fuji Green in Commercial Packages

For Figure 12, the curve shows a ΔE of 3.69 at the 50 percentile, 5.49 at the 90 percentile, and 5.80 at unity.

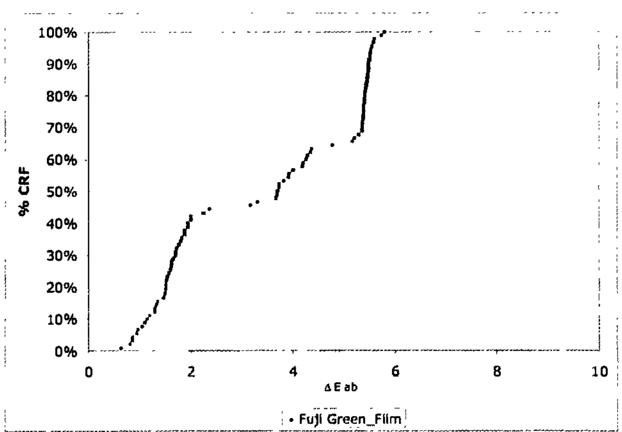

Figure 12. CRF Curves of Fuji Green in Commercial Packages

According to the findings, Fuji Green on film packages shows less color variation than Kodak Yellow in terms of ΔE. It also shows the same manufacturing batch-to-batch variation as Kodak's.

6.1.3. Coca Cola Red

For Coca Cola Red packages, the maximum, minimum, and average L*a*b* value are shown in Table 5. From Table 5, the variation for b* is the largest among three axes.

	L*	a*	b*
Min.	40.7	66.5	43.9
Max.	45.5	72.8	56.9
Ave.	43.8	70.8	49.8

Table 6. CIE LAB of Coca Cola Red in Commercial Packages

Figure 13 shows the location of Coca Cola Red. The samples vary mostly along the b* axis.

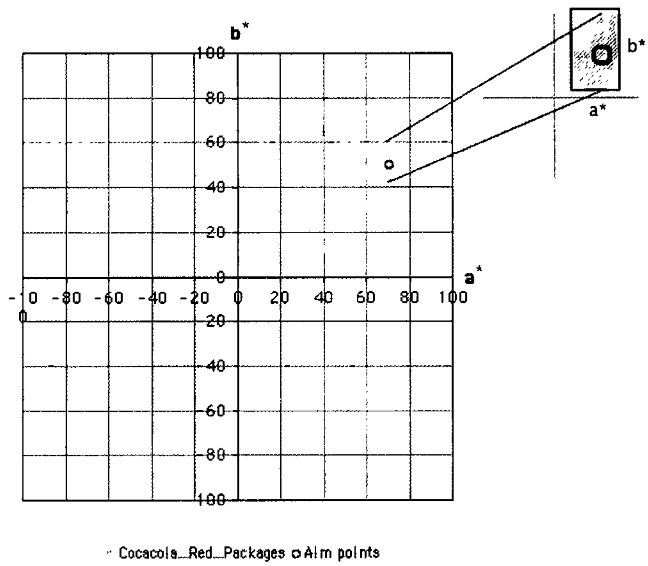

Figure 13. a* b* Diagram of Coca Cola Red in Commercial Packages

From Figure 14, the dot along b* axis is the most dispersed. The line through the samples shows that the error is constant in hue but varying in saturation.

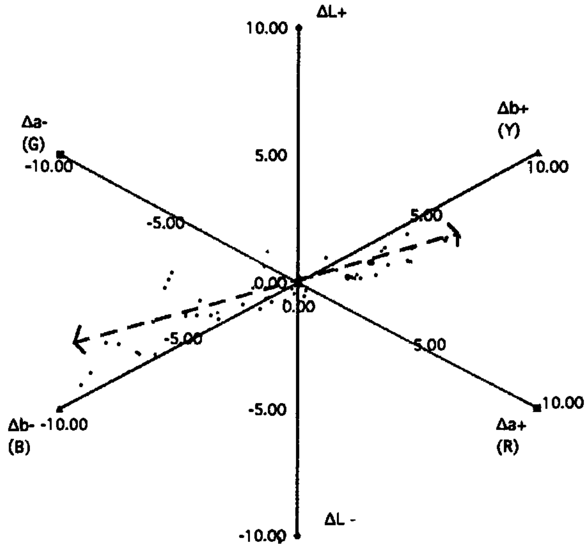

Figure 14. Three Dimensional Lab Plot of Coca Cola Red in Commercial Packages

CRF for Coca Cola red shows a ΔE of 2.50 at the 50 percentile, 5.58 at the 90 percentile, and 7.32 at unity. According to the results, Coca Cola Red has a much larger b* variation than a*.

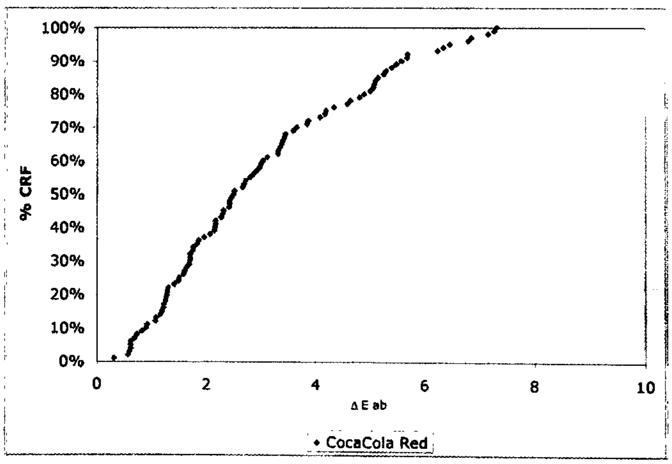

Figure 15. CRF Curves of Coca Cola Red in Commercial Packages

6.1.4 Sunkist Orange

For Sunkist Orange packages, the maximum, minimum, and average L*a*b* values are shown in Table 6.

	L*	a*	b*
Min.	58.4	49.6	72.0
Max.	63.6	58.4	77.7
Ave.	61.4	55.8	75.7

Table 7. CIE LAB of Sunkist Orange in Commercial packages

Figure 16 shows the plot of the Sunkist package samples. They are lightly clustered about a mean orange hue.

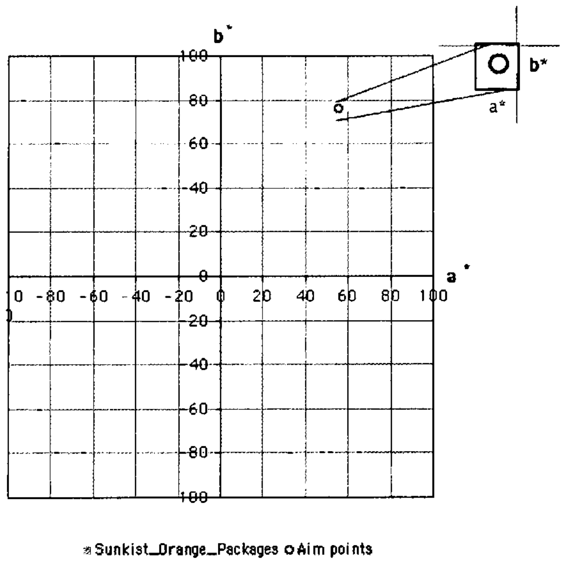

Figure 16. a* b* Diagram of Sunkist Orange in Commercial Packages

Figure 17 shows that the scatter of the Sunkist in random with respect to hue with little variation in lightness. This process is well controlled with variation within 3.0 Δ E.

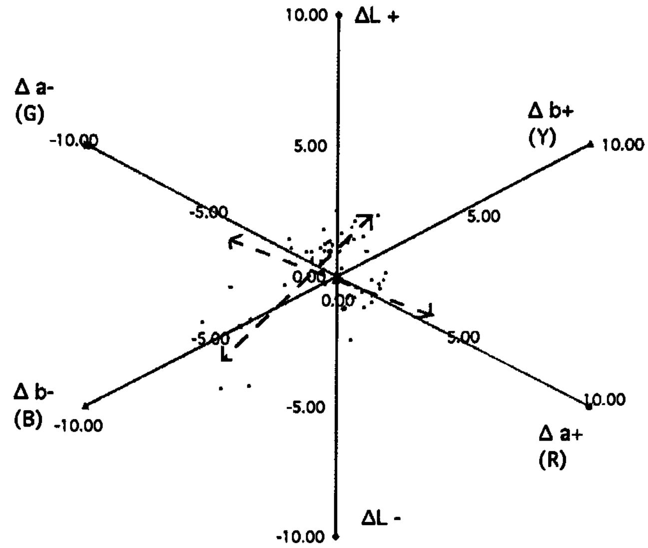

Figure 17. Three Dimensional Lab Plot of Sunkist Orange in Commercial Packages

Figure 18 shows the CRF curve ΔE of 1.42 at the 50 percentile, 3.07 at the 90 percentile, and 6.62 at unity.

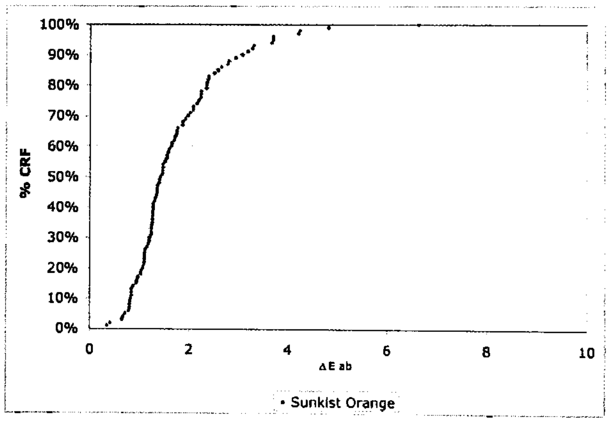

Figure 18. CRF Curves of Sunkist Orange in Commercial Packages

According to the findings, Sunkist Orange packages show small variations relative to Fuji Green or Kodak Yellow film packages. Also, the differences between a* and b* are not significant.

6.1.5 Chips Ahoy Cyan

For Chips Ahoy Cyan packages, the maximum, minimum, and average L*a*b* are shown in Table 7.

	L*	a*	b*
Min.	42.0	-31.4	-55.4
Max.	48.8	-25.7	-50.3
Ave.	44.6	-28.4	-53.1

Table 8. CIE LAB of Chips Ahoy Cyan in Commercial Packages

Figure 19 shows both the location and variation of sample dots for Chips Ahoy cyan packages. The variation of samples shows that a* is a little larger than b*.

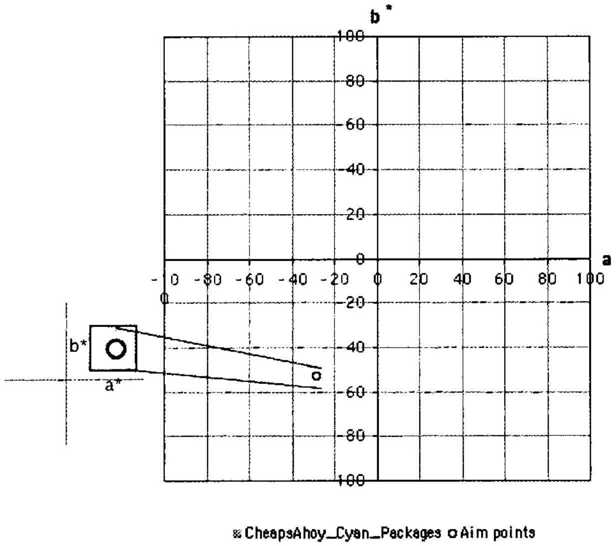

Figure 19. a* b* Diagram of Chips Ahoy Cyan in Commercial Packages

From the Lab axis in Figure 20, the samples are dispersed along the L* axis. Considering the variation of L*, that of both a* and b* are relatively small.

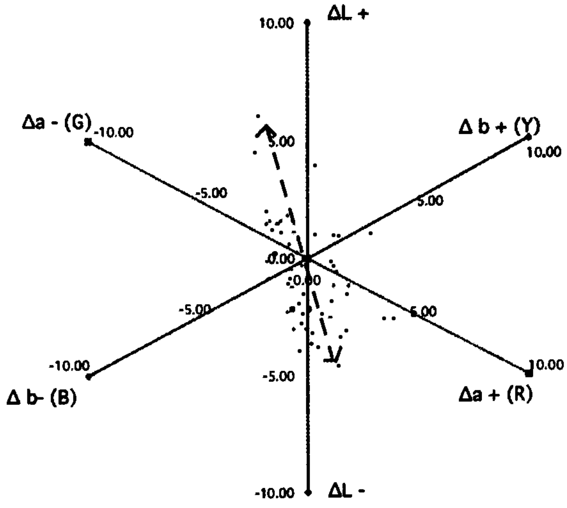

Figure 20. Three Dimensional Lab Plot of Chips Ahoy Cyan in Commercial Packages

For Figure 21, the curve shows that ΔE of 1.82 at the 50 percentile, 3.18 at the 90 percentile, and 5.43 at unity.

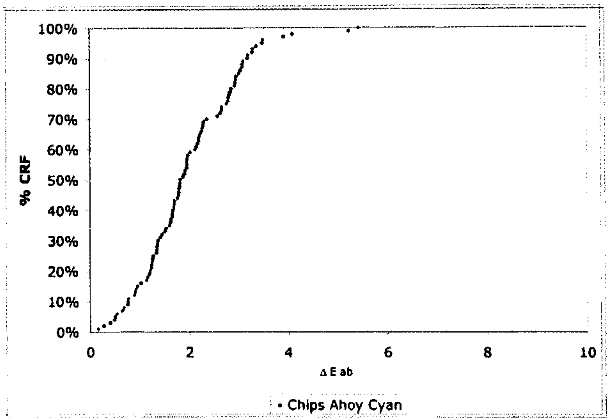

Figure 21. CRF Curves of Chips Ahoy Cyan in Commercial Packages

According to the findings, Chips Ahoy cyan packages has the small variation as Sunkist Orange packages in terms of ΔE. The major variation is in the lightness dimension but is still enough to be considered well in control.

6.1.6 Pepsi Deep Blue

For Pepsi deep blue, the maximum, minimum, and average L*a*b* of packages are shown in Table 8.

	L*	a*	b*
Min.	18.8	3.7	-57.8
Max.	26.1	13.4	-42.5
Ave.	22.2	7.9	-51.2

Table 9. CIE LAB of Pepsi Deep Blue in Commercial Packages

Figure 22 tells that Pepsi has a much larger b* variation than a*. For the location, the sample is plotted mostly between the magenta and blue area toward the less saturation area.

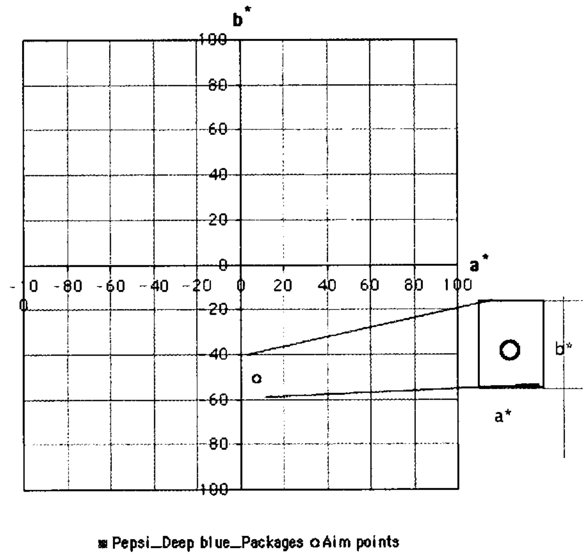

Figure 22. a* b* Diagram of Pepsi Deep Blue in Commercial Packages

From the Lab axis in Figure 23, the dot along the L* axis is the most disperse same as in the sample for Chips Ahoy Cyan.

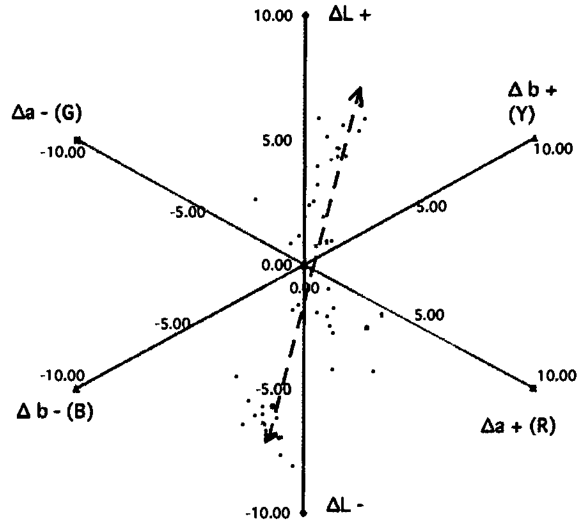

Figure 23. Three Dimensional Lab Plot of Pepsi Deep Blue in Commercial Packages

For Figure 24, the curve shows that ΔE of 4.36 at the 50 percentile, 7.45 at the 90 percentile, and 10.20 at unity.

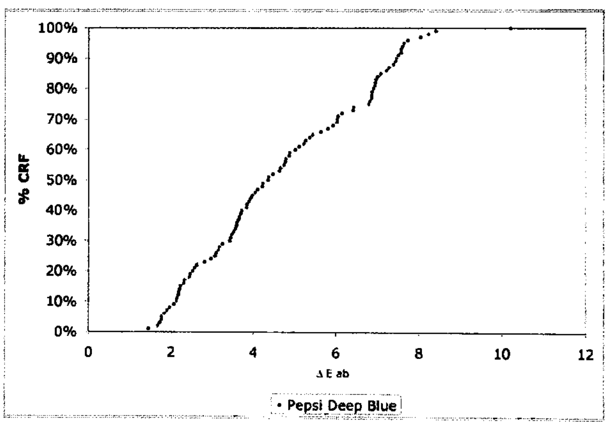

Figure 24. CRF Curves of Pepsi Deep Blue in Commercial Packages

According to the findings, Pepsi Deep Blue on packages shows a significant variation by not only b* but also L*. The nature of the variation shows that the printers were not controlling density in the packaging production.

6.1.7. Alpha Bits Magenta

For Alpha Bits magenta packages, the maximum, minimum, and average L*a*b* values are shown in Table 9.

	L*	a*	b*
Min.	36.8	50.8	-20.6
Max.	48.4	59.0	-15.3
Ave.	39.7	56.6	-17.8

Table 10. CIE LAB of Alpha Bits Magenta in Commercial Packages

Figure 25 shows that it has a slightly larger a* variation than b*.

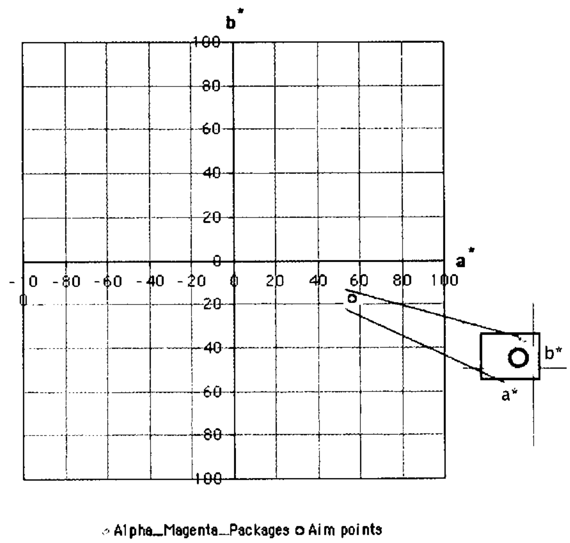

Figure 25. a* b* Diagram of Alpha Bits Magenta in Commercial Packages

From Figure 26, the samples are close to the reference, even though it has a small variation along the a* axis.

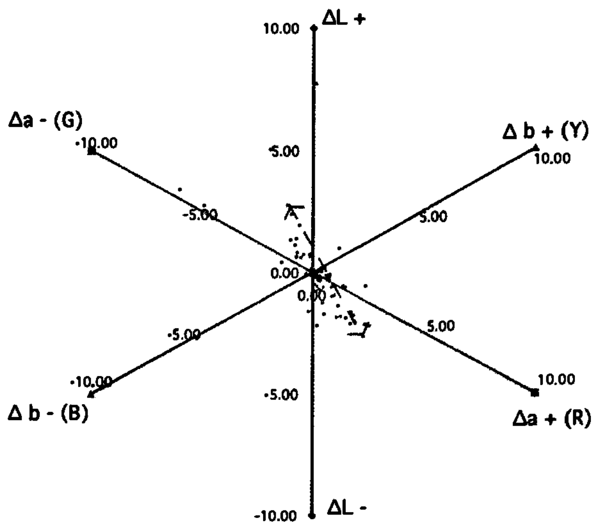

Figure 26. Three Dimensional Lab Plot of Alpha Bits Magenta in Commercial Packages

For the Figure 27, the curve shows ΔE of 1.78 at the 50 percentile, 3.49 at the 90 percentile, and 8.66 at unity.

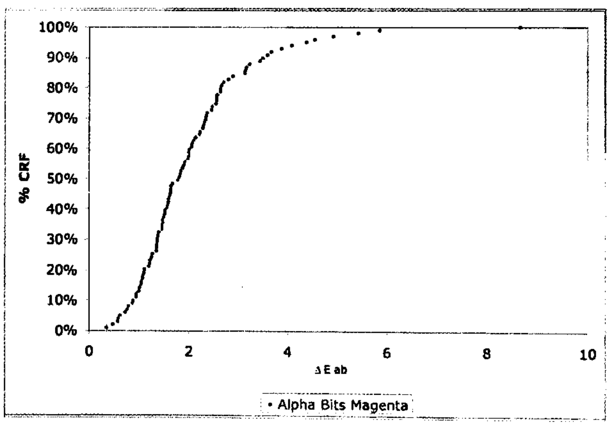

Figure 27. CRF Curves of Alpha Bits Magenta in Commercial Packages

6.2 The Variation of Brand Color on Commercial Packages

Each brand color has different performance in terms of color matching. Since the brand color is measured by a spectrophotometer, the color match should be $\Delta E < 2$. Assuming that the expectation of the company for brand color is $\Delta E < 2$, the average for Sunkist orange, Chip's Ahoy cyan and Post Alpha Bits magenta is less or around ΔE of 2.0. However, for 90 percentile of sample, none of the samples for brand color is $\Delta E < 2$ from Table 11.

Color	Brand	ΔE statistics			
		Average	50 percentile	90 percentile	Unity
Yellow	Kodak	4.21	3.60	8.26	10.45
Green	Fuji	3.29	3.69	5.49	6.43
Red	Coca Cola	3.00	2.50	5.58	7.32
Orange	Sunkist	1.76	1.42	3.07	6.62
Cyan	Chips Ahoy	2.00	1.82	3.18	5.43
Deep Blue	Pepsi	4.69	4.36	7.45	10.20
Magenta	Post Alpha Bits	2.08	1.80	3.49	8.66

Table 11. ΔE Statistics of Brand Color in Commercial Packages

Figure 28 shows the comparison of CRF curves for each brand color. From Figure 27, Sunkist orange has the smallest color difference; whereas, Kodak yellow has the largest color difference. The CRF curve for Post Alpha bits magenta and Chip's Ahoy cyan is close to Sunkist orange, which means that those have relatively small color difference. Also, the CRF for Pepsi deep blue is close to Kodak yellow, which means Pepsi has relatively large color difference.

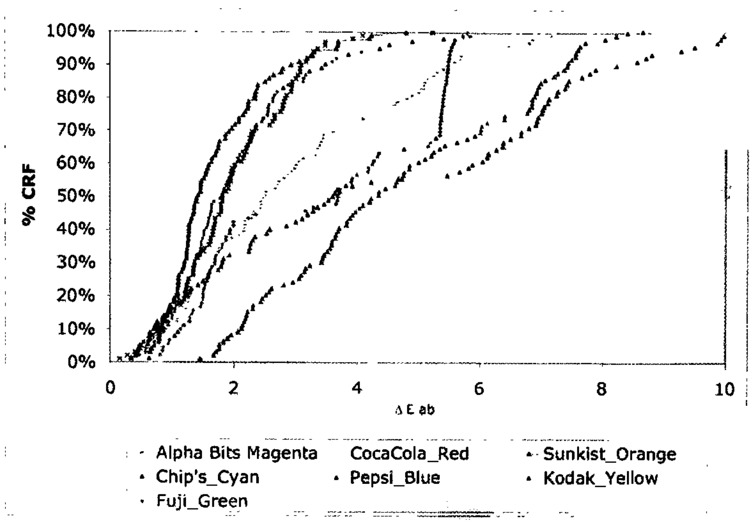

Figure 28. CRF Curves of Brand Color in Commercial Packages

6.3 Brand Color on Magazine Advertising

For the magazine advertisement, the variability of specified Kodak Yellow and Fuji Green brand color was determined and compared by measuring CIE LAB.

6.3.1 Kodak Yellow

According to the sample data, the maximum, minimum, and average values are acquired as shown in Table 11. The average value was used on reference value to determine the variation in the advertisement.

	L*	a*	b*
Min.	70.1	7.7	61.7
Max.	79.6	20.6	85.2
Ave.	74.5	14.9	71.1

Table 12. CIE LAB of Kodak Yellow in Magazine Advertising

Figure 29 indicates for both location and variation of Kodak Yellow of magazine advertisement. Considering a*b* slice for film packages, the overall variation is much larger than that of film packages. The variation along b* is much larger than a*.

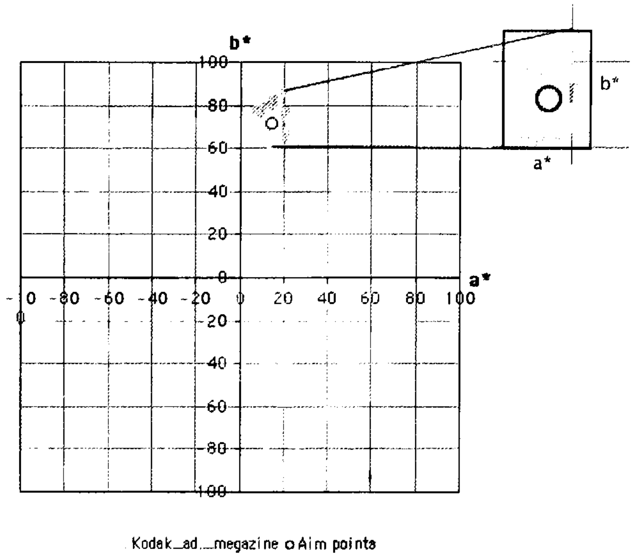

Figure 29. a* b* Diagram of Kodak Yellow in Magazine Advertising

From the Lab axis in Figure 30, the center point is the average of the data. The plotted dots are the variation from the reference. As shown in Figure 29, samples are widely dispersed, and some of them are over ΔE of10. Also they don't show any particular direction or clustering.

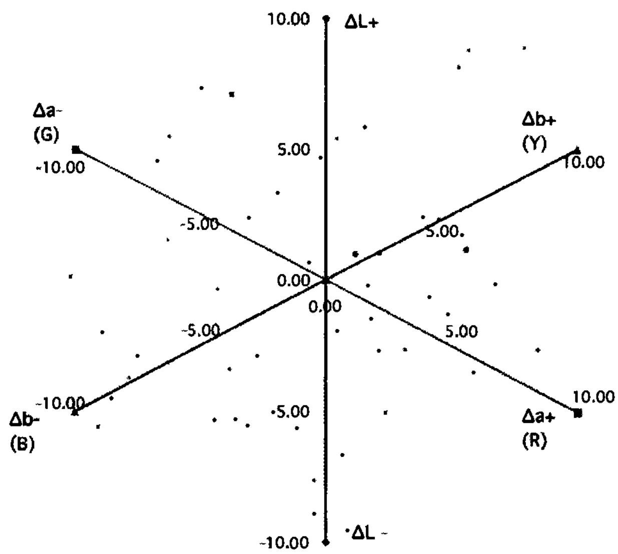

Figure 30. Three Dimensional Lab Plot of Kodak Yellow in Magazine Advertising

The Cumulative Relative Frequency (CRF) shows the quantitative analysis of color differences between film package and magazine advertising. From Figure 31, the CRF curve for magazines shows that ΔE of 6.10 at the 50 percentile, 9.51 at the 90 percentile, and 15.12 at unity while the CRF curve for the film package has the ΔE of 3.60 at the 50 percentile, 8.26 at the 90 percentile, and 10.45 at unity.

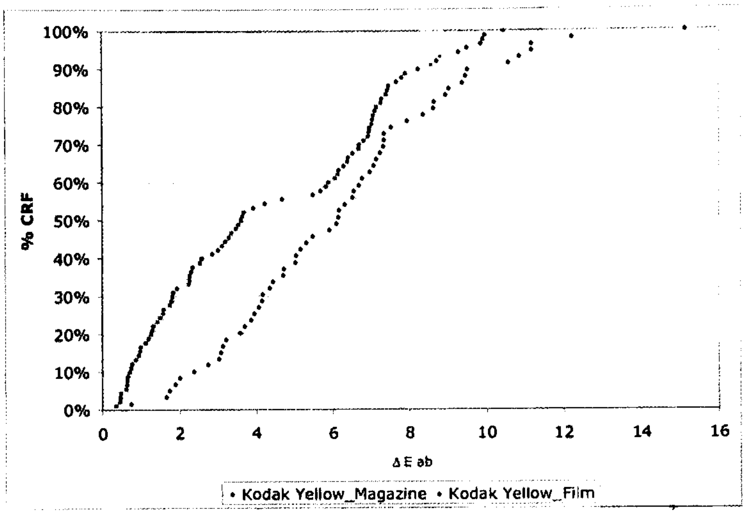

Figure 31. CRF curves of Kodak Yellow in Commercial Packages and Magazine Advertising

<u>6.3.2. Fuji Green</u>

For Fuji Film, the maximum, minimum and the average L*a*b* are shown as Table 12 in advertising

	L*	a*	b*
Min.	45.1	-63.2	15.3
Max.	59.5	-46.3	41.3
Ave.	54.4	-56.5	27.6

Table 13. CIE LAB of Fuji Green in Magazine Advertising

Figure 32 indicates both a* and b*variations for Fuji green on magazine advertisement. The overall variation is greater than that measured for film packages. Between a* and b*, the variation along b* is much larger than variation seen in a*.

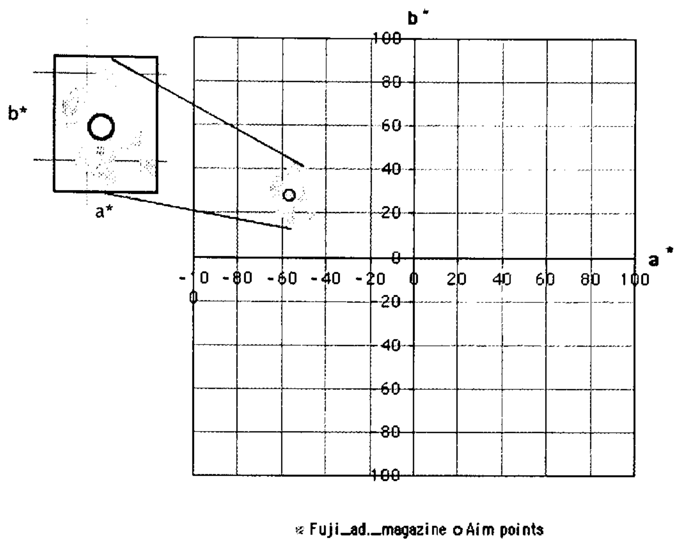

Figure 32. a* b* Diagram of Fuji Green in Magazine Advertising

From Figure 33, the dots from the sample are widely dispersed, but most of them are inclined to be plotted by the b*axis.

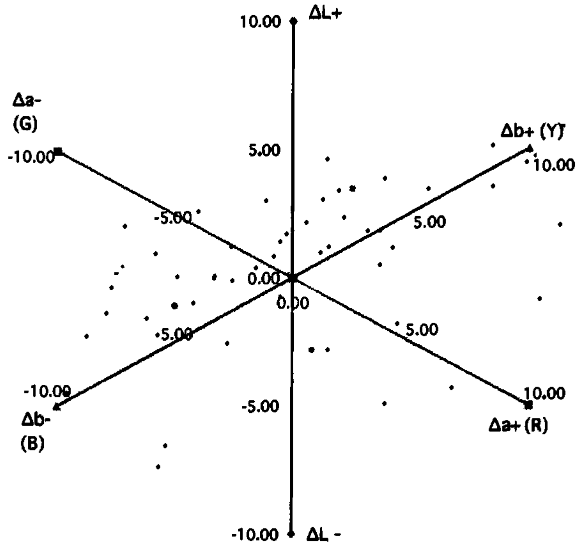

Figure 33. Three Dimensional Lab Plot of Fuji Green in Magazine Advertising

From Figure 34, the CRF curve for magazine shows a ΔE of 5.54 at the 50 percentile, 10.82 at the 90 percentile, and 16.72 at unity. While the CRF curve for the film package has the ΔE of 3.69 at the 50 percentile, 5.49 at the 90 percentile, and 5.80 at unity.

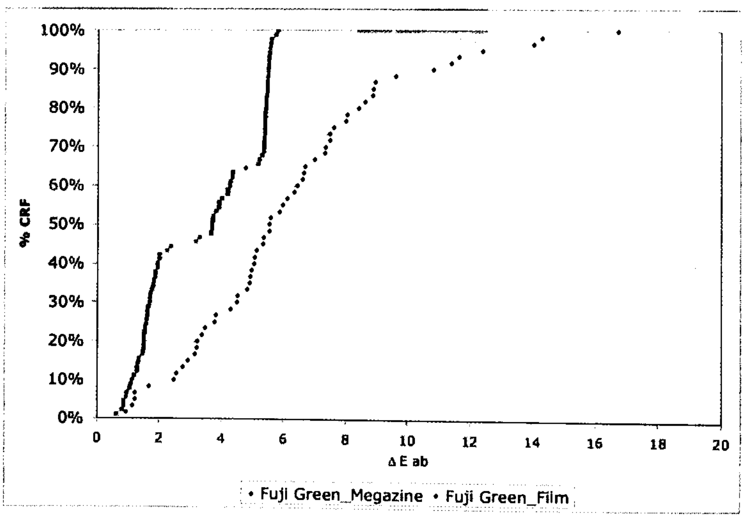

Figure 34. CRF curves of Fuji Green in Commercial Packages and Magazine Advertising

6.4 The Variation of Brand Colors between Commercial Packages and Magazine Advertising

From the aspect of color matching, the variation of brand color for magazine advertising is much larger than that for film packages. Kodak Yellow shows 4.67 ΔE difference, while Fuji Green has 10.71 ΔE difference.

Color	Brand	Media	ΔE statistics			
			Average	50 percentile	90 percentile	Unity
Yellow	Kodak	Film Packages	4.21	3.60	8.26	10.45
Yellow	Kodak	A.D. Magezine	4.38	6.10	9.51	15.12
Green	Fuji	Film Packages	3.29	3.69	5.49	6.43
Green	Fuji	A.D. Magezine	6.20	5.54	10.82	16.72

Table 14. ΔE Statistics of Brand Color in Commercial Packages and Magazine Advertising

Figure 35 shows the comparison of CRF curves between magazine advertising and film packages. From Figure 36, brand color for film packages has a smaller color difference than that for magazine advertisements.

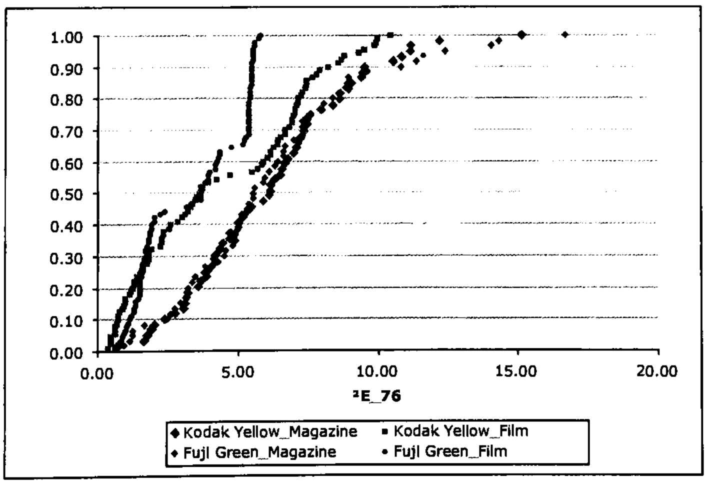

Figure 35. CRF curves for Brand Colors in Commercial Packages and Magazine Advertising

Chapter 7

Conclusion

The purpose of this research is to find out what variability of brand colors exists in commercial packaging and magazine advertising by measuring the CIE LAB value of samples.

7.1 Ha: (alternative hypothesis) accepted

According to findings in chapter 6, each brand color for commercial packaging shows different performance in terms of color matching. The color match should be $\Delta E < 2$. From the aspect of the 90 percentile of samples for each brand color, none of the samples is $\Delta E < 2$. Assuming the expectation of the print service providers is that the sample for brand color should fall inside acceptable tolerances, the alternative hypothesis (Ha) is accepted; with respect to the measurement of the accurate reproduction of brand colors, the actual performance of print services providers shows variation in color reproduction that exceeds acceptable tolerances for color matching.

7.2 The Variation of CIE LAB Axes for Each Brand Color

For the samples of solid brand color, seven brand colors are selected based on the hue circle. Samples of each brand color show the different variation in terms of ΔE and move toward along the CIE LAB axes differently. This result shows that controlling the variation of brand color should consider the nature of the variations.

The average for Sunkist orange, Chips Ahoy cyan and Post Alpha Bits magenta is less or around ΔE of 2.0. By Comparison, other colors are well controlled with color matching, although the 90 percentile of samples for those is $\Delta E > 2$.

Based on these findings, the companies for color match should be specified and controlled by not only ΔE but also by different variations of the CIE LAB axes.

7.3 Comparison between Different Print Media

From the aspect of color matching, the variation of brand color for magazine advertising is much larger than that for film packages. Kodak Yellow shows 4.67 ΔE difference, while Fuji Green has 10.71ΔE difference. This is primarily due to the wide range of substrates and process colors used in magazine advertising. It is also concluded that the expectation of the companies for specifying color should be different for each type of print application.

7.4 Recommendation for Further Investigation

In this study, the actual performance of the printing industry with respect to brand color is analyzed by CIE LAB based on the color difference. There is a question about how well

CIE LAB represents the color variation that people accept. A further study on this topic requires that the color tolerance of brand color specified by each company should represent the color variation people accept.

Also, this study is about the general research on variation for brand color reproduction in a variety of print applications, but for further investigation, it is recommended that the variation should be determined for each print process by media application. Further, a study of tolerance of spot colors and their CMYK process equivalent should be considered.

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