Analysis of Spectral Response Variation Among Multiple Color Measuring Devices (Spectrophotometry) In a Color Managed Workflow (CMW)

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Keywords: calorimetry, spectrophotometry, ANOVA, color, color management, workflow

Abstract

Color Management Workflow (CMW) uses a set of hardware tools and software applications working together to create accurate color between various input, display, and output devices. The purpose of this study was to determine the colorimetric deviation of multiple types of spectrophotometers. A total of five types of instruments were used in the experiment. Modern printing technology has evolved from the craft oriented field toward a color management science demanding greater color reproduction and control among the devices used in the print and imaging industry. This is of importance to the graphic communication educator as the tools used to control those interface are increasingly software applications and instruments that invite the knowledgeable student to manipulate (or use) the default settings to achieve superior color results. In seeking to empower our students to better understand the color deviation, this work examined the use and operation of multiple spectrophotometers in a laboratory environment, similar to, upon entering into the workplace, a student would encounter. Hence for a student to consistently deliver

a quality print, managing and controlling color from the input device to a multicolor output device is a major concern for the graphic arts educator. Color can be viewed as a science where the optical aspects of color are quantitatively analyzable and measurable with the use of multiple types of color measuring devices, such as: Colorimeters, Densitometers, and Spectrophotometers. However, this study examined only the use of spectrophotometers. Applying these devices with our students will heighten their recognition as to the importance of proper color workflow.

1. Introduction

A spectrophotometer takes the subjective judgment out of how a printed image looks. This device makes color imagery a science. There are three main categories that determine the quality of an image; the light itself, the object that is reflecting the light, and the observer. Spectrophotometers only determine light and not how the observer is going to interpret the light spectrum. Images are still up for interpretation to the end viewer, but we can consistently measure the image to achieve objective and quantifiable numbers. These machines measure the spectrum of light and its intensity. "Color measurement variation can stem from the substrate, such as paper, and how spectral reflectance data are collected" (Chung & Liu, 2008). Most machines look at some of the ultraviolet and infrared spectrum as well as the visible. This is needed for several applications for imagery. These two other spectrums can heavily influence the visible light spectrum. The first is the interaction of these spectrums with the human visual spectrum. UV and infrared can change the appearance of the visual light spectrum (Chung & Liu, 2008). One way of doing so is altering the chemicals in the materials that we use for printing. These materials can produce a fluorescent or phosphorescent effect on the image. One large factor with materials is the introduction of optical brightening agent (OBA) on printing paper. Assessing how color is measured is important to the reliability of the measurements. Companies may describe their product similar to that of other companies, but may not actually yield the same properties due to the variation in tests and methods used (Chung & Liu, 2008).

The paper for printing can have a large factor in the final quality of the image. "Paper is considered a commodity but its properties are a long way from standardized" (Wales, 2008). Companies may use tools like a spectrophotometer to determine aspects about their product, but there are a wide variety of methods and applications that the spectrophotometer can be used. Chung & Liu (2008) conducted a study to determine the magnitude and difference of variety of colorimetric differences, and whether or not UV light spectrum should be included in color agreement. Optical brightening agents can cause inclusion and exclusions that cause errors in color measurement (Chung & Liu, 2008). The other large area to consider why two non-visual light spectrums are needed is that not all imagery involves human perception of color and images. Some species of birds can see into the UV range and have a four pigment eye, compared to the human three. Spectrophotometers are used in a wide range of applications. With the usage of a spectrophotometer, the plumage coloration, chroma and hue can be determined for birds (Quesada & Carlos, 2006). Without the use of machines like the spectrometer it would be impossible to gain a clear understanding of a birds' plumage color. Determining the degradation of printed images is one area of benefit for these devices (or instruments).

Printed colors start to deteriorate as soon as they are printed. Most photographic technology prints will heavily degrade after about fifty to one hundred years after its initial print. The importance of a spectrophotometer is that it can measure the degradation of an image when it is exposed to certain environmental factors. This allows for determining which factors play the most crucial role in the longevity of printed images. This also can help determine which inks and pigments are to be used for specific applications of prints. Other distortions may happen to images during the printing process. The International Color Consortium (ICC) color management system provides set standards for color management across different platforms. Even with the standards, an experiment conducted by Hermachand Kolli attempted to see the distortions of images as different color management systems handle images. This experiment showed that "visual assessment and colorimetric analysis agree with each other in that there was no hue shift between the original and reproduction, and that the dark colors were clipped." The main idea of this experiment was that every program that the image was transferred to would maintain the picture in its original form, but distorted in some way. The main idea behind the use of a spectrophotometer is that it gives a quantifiable measurement of the end result. There are a lot of factors that may affect the quality of the print.

The two most common geometries found in modern instruments are diffuse/8 and 45/0 (Butts, Color Measurement for package Dyeing). Diffuse/8 is a measurement that is taken from an eight degree angle vertical of the surface. A spherical light source is used to illuminate the surface using the same angle position. This method minimizes the influence of surface irregularities on light reflected from the sample and is useful for shade matching and for measuring the pure color of the print (Butts, Color Measurment for Package Dyeing). 45/0 method used with a spectrometer conducted by having the light source at a 45 degree angle and then having the collected light be measured perpendicular to the surface. This method takes surface structure more into account compared to the diffuse/8 method. The 45/0 is use to give a reliable and measureable test to how an image would appear to the viewer. The problem with these methods is that they will not produce the same results. This means that companies have to use the same method to do an even comparison of measurements taken from the spectrophotometer. The differences of these methods are the use of two different light sources. Tungsten filament and xenon bulbs are used in spectrophotometers. Tungsten bulbs produce a good spectrum of light for sapling, but produce a considerable amount of heat, which may or may not affect the characteristics of the surface of the sample. Xenon bulbs don't produce any considerable amount of heat compared to the tungsten bulbs. Xenon bulbs produce more light in the UV spectrum. This may excite any fluorescent or phosphorescent properties of the test piece. White tile test are used to perform calibration to spectrophotometers and are used with either diffuse/8 or 45/0 methods.

Color can be viewed as a science where the optical aspects of color are quantitatively analyzable and measurable. The human eye, however, perceives color more subjectively, which poses a challenge at times for the print and image reproduction industry. Advancements in science and engineering however have allowed print and graphic professionals to apply scientific research methods across prepress, pressroom, and quality control. Applying these methods heightens the importance of proper workflow. Workflow is represented through schematic illustrations of activities that reflect the systematic organization of analog and digital devices used during the print and image production process. In many cases, an image and its various attributes are captured by digital input devices such as scanners and cameras. The image's features are then stored as a data file, likely manipulated and later printed by an array of output devices including digital printers or a printing press. Accurate or facsimile color control from beginning to end in a printing or imaging process is important for quality output whether as a display or in print. Given each family of devices tends to create and produce color differently; the challenge is to manage color consistency across the entire workflow. In particular, input and output devices produce colors differently because they depend on their own color capabilities. Color management as a workflow activity simplifies and improves the reproduction accuracy of color images from device to device. When appropriately used in the print process, a Color Management System (CMS) will assist the producer in delivering accurate output colors regardless of device color capacities with the use of proper gamut mapping techniques.

2. Colorimetry/Spectrophotometry

As stated earlier, spectrophotometer measures the amount of light reflected from a surface. The result will be a dataset of reflectance values that represents the spectral distribution of the light reflected from the point of the measurement. This means that the starting point will be at 380 nanometers (nm). The spectrophotometer then controls how much of the particular wavelength is reflected. The result will be a percentage value. This procedure is then repeated for the entire spectrum (each wavelength) and the resulting dataset can be visualized as a spectral curve. The visible spectrum normally ranges from 380 nm to 780 nm and most spectrophotometers sample it every 10^{th} nm. This data is general and can vary depending on the device being used. When comparing data in colorimetry, it is important to consider both the structure of the device and the illumination source. A spectrophotometer is the most accurate instrument with which to measure color. The spectral distribution curve can also be used to calculate densitometric and colorimetric values. Spectral response values can be obtained in CIE XYZ and L* a* b* scales.

2.1. CIE L* a* b* Color Model

The Commission Internationale de l'Eclairage (CIE), (in English, the International Commission on Illumination) makes international recommendations for colorimetric measurements (ANSI/CGATS.5-2003). In 1976, the CIE developed the CIE L*a*b* or CIELAB color model (scale) for quantifying color values numerically. It was intended to be a standard, approximately uniform color model that industry could use to compare and express color values (ANSI/CGATS.5-2003). The CIE color model utilizes three coordinates to locate a color in a color model. In a uniform color model, the differences between points plotted in the color model correspond to the visual differences between the colors plotted (Hunter Lab, 1996). The CIELAB color space takes the form of a cube. The L* axis runs from top to bottom. The maximum for L* is 100, which represents a perfect reflecting diffuser. The minimum for L* is 0, which represents black. The +a* and +b* axis have no specific numerical limits. A +a* is an indication of red color and –a* is green color in the color model. Additionally, +b* is yellow and –b* is blue. The center of this model represents neutral or gray colors. These color scales are based on the opponent color theory of color vision, according to which two colors cannot be both green and red at the same time, nor blue and yellow at the same time. As a result, single values can be used to describe the red/green and the yellow/blue attributes (X-Rite, 2002). The following equations are used by the spectrophotometer to calculate the CIE L* a* b* values (ANSI/CGATS.5-2003).

$$L^* = 116\left(Y/Y_n\right)^{1/3} - 16$$
$$a^* = 500\left[\left(X/X_n\right)^{1/3} - \left(Y/Y_n\right)^{1/3}\right] \quad [1]$$
$$b^* = 200\left[\left(Y/Y_n\right)^{1/3} - \left(Z/Z_n\right)^{1/3}\right]$$

where: Xn, Yn, Zn: Tristimulus Values of XYZ for 2° Standard Observer

2.2. CIE Color Difference (ΔE)

Assessment of color is more than a numerical expression. In most cases it's an assessment of the deviation in the color sensation (delta) from a known standard. In CIELAB color model, any two colors can be compared and differentiated. These color differences are expressed as ΔE (Delta E or Difference in Color Sensation). The following equation is used to calculate the ΔE (ANSI/CGATS.5-2003, p.29).

$$\Delta E^* = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2} \quad [2]$$

where: 1 = Color 1 and 2 = Color 2

2.3. Overview of Color Management System (CMS)

Color Management Workflow (CMW) or CMS uses a set of hardware tools and software applications working together to create accurate color between various devices: input, display, and output. A CMS consists of device profiles (or characterization of devices) which control and document the working performance of the scanner, monitor, and the printer. A device color transformation engine (Color Management (matching) Module (method) or CMM) is one that interprets the color data between the scanner, display, and the printer. The gamut compensation mechanism of the CMS addresses differences between the color capabilities of input, display and output devices. The Profile Connection Space (PCS) is a device independent color space through which all color transformation occurs from one device-dependent color space to another (see Figure 1). The PCS is based on the spaces derived from CIE color space. Apple ColorSync supports two of these spaces: L* a* b* and XYZ. The color conversion from device-dependent color space to device-independent color space is achieved by the use of PCS. The device color characterization file (profile) passes in and out of the PCS to complete the transformation. The PCS is the central hub of the CMS in which a particular color value is considered absolute and not subject to interpretation.

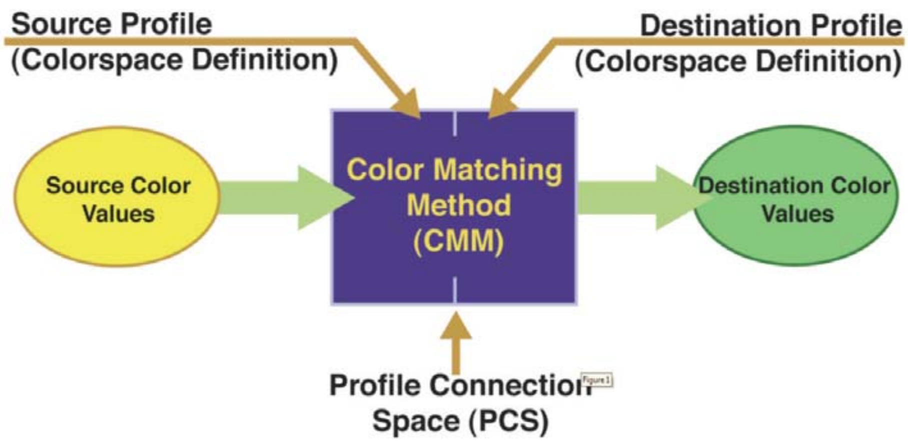

Figure 1: *Schematic of PCS of CMS (Courtesy of Adobe Systems, Inc.)*

The International Color Consortium (ICC) was formed in 1993 by seven industry members (Adobe, Agfa, Apple, Kodak, Microsoft, Sun Microsystems, and Silicon Graphics) to define the standards for color device characterization (Adams & Weisberg, 2000). Today, the ICC represents more than seventy industry and honorary members (ICC, 2009). This device characterization is presented in terms of specially formatted files, which have come to be called profiles. Unfortunately, the use of color management systems has not yet solved all of the problems of color reproduction (Fleming & Sharma, 2002), such as: acceptance of linear colors, reproduction of neutral gray-balance, rendering and intents, however, it has made possible the quantification of problems. As always, in quality control, with quantification comes the ability to control and, with control, quality management becomes possible (Fleming & Sharma, 2002).

2.4. The 4 C's of CMS or CMW

To implement the CMS successfully, all the devices (monitor, scanner or digital camera, and printer or printing press) which are used for printing and imaging purposes must be calibrated, characterized (profiled) and their color capabilities (RGB and CMYK) must be converted into an independent color space (CIE L* a* b* space). A calibration process means standardizing the performance of the devices according to the device manufacturer specifications so that the results of the devices are repeatable. A profiling process (or characterization) refers to colorimetric assessment of the device color performance and creating an ICC (International Color Consortium) profile specific to that device. The characterization process requires CMS hardware tools and software. Characterization of the devices is converted into an ICC profile file format. It communicates measured color output of devices in response to known output. Conversion refers to translating a color image data from one device color space to another device space. It is also known as color transformation. Control, the fourth C, means the user of CMW must monitor and analyze the use of the CMW process through the use of statistical process control (SPC) tools in order to avail the benefits of the CMW.

3. Purpose of the Research

The experiment was conducted in a color managed workflow (CMW) to determine the spectrophotometers response variation of a color based on the statistical evaluation among the five different types of spectrophotometers (color measuring devices or instruments). It focused on the measurement of color prints, printed by using cyan, magenta, yellow, and black (CMYK) dry-toners on a digital color printing device which uses a color laser digital printing technique (color electro-photography). The objective was to study the device response variation in a CMW. The following one-tailed non-directional hypothesis was established, because of the multiple devices (groups, K = 5).

H_o: There is no difference (or relationship) in the average ΔE of multiple devices color response, when comparing the printed colorimetry against the reference colorimetry.

H_a: There is difference (or relationship) in the average ΔE of multiple devices color response, when comparing the printed colorimetry against the reference colorimetry.

3.1. Limitations of the Research

This experiment is limited to the technology used within the graphic communications management program laboratory. Prior to printing and measuring the samples, the digital color output printing device and color measuring instruments (spectrophotometer and densitometer) were calibrated against the recommended reference. The print condition associated with this experiment is characterized by, but not restricted to, inherent limitations, for example: colored images chosen for printing, type of digital printer for proofing/printing, type of paper for printing, type of toner, resolution, and screening technique, use of predefined color output profiles, and calibration data applied, etc. There are several variables affecting the facsimile reproduction of color images in the CMW and most of them are mutually dependent on each other. The scope of the research was limited to the color laser (electro-photographic) digital printing system (printing proof/printing) and other raw materials and the multiple types of color measuring devices and color management and control applications (data collection, data analysis, profile creation, and profile inspection) used at the university graphic communications laboratory. Findings were not expected to be generalizable to other CMW environments. It is quite likely, however, others could find the method used and the data of the report meaningful and useful. The research methodology, experimental design, and statistical analysis were all selected in alignment with the purpose of the research with full awareness of the aforementioned delimitations.

4. Research Method

The digital color output device used in this experiment is a Xerox DC250 CMYK printer (or digital press). It uses a Creo Spire CX250 raster image process (RIP) server (front-end system). This study utilized an experimental research method. MOHAWK brand 80 LBS matte-coated digital color printing paper was used. It was intended to determine the color differences of multiple color measuring devices in a color managed workflow (CMW). A total of five different types of spectrophotometers were used. Each device in the experiment was considered as a group, noted by letter “K” (K = 5). For all the five groups, a total of 100 samples were printed, noted by letter “N” (N = 100). Of 100 samples, 80 samples were randomly selected, and measured, noted by letter “n” (n = 80). Multiple types of ICC standard based color management applications (software) and instruments were used in the experiment. A detailed method of this experiment is summarized in the following paragraphs. The digital color printing laboratory uses color management workflow for accurate color reproduction.

4.1. Printer Calibration

One of the important issues in getting acceptable print quality is the stable level of toner density (printer density). It fluctuates due to many controlled and uncontrolled variables, such as: room humidity, temperature, printer settings, paper, age of toner, and inaccurate calibration or linearization of the printer, etc. As such, the daily calibration of the printer is very important. The calibration process for the printer used in the experiment was performed per the guidelines given by the device manufacturer. The CMYK calibration chart (with various tonal gradations) was printed without using any previous calibration data with 200 LPI (see Figure 2). An X-Rite DTP34 Scanning (Quick Cal) densitometer was used to scan the printed chart. The densitometer was calibrated against its reference chart prior to using it to calibrate the printer (or measure the chart). The calibration data (CMYK density ranges) was saved in the calibration look-up tables and a calibration curve was created (see Figure 3).

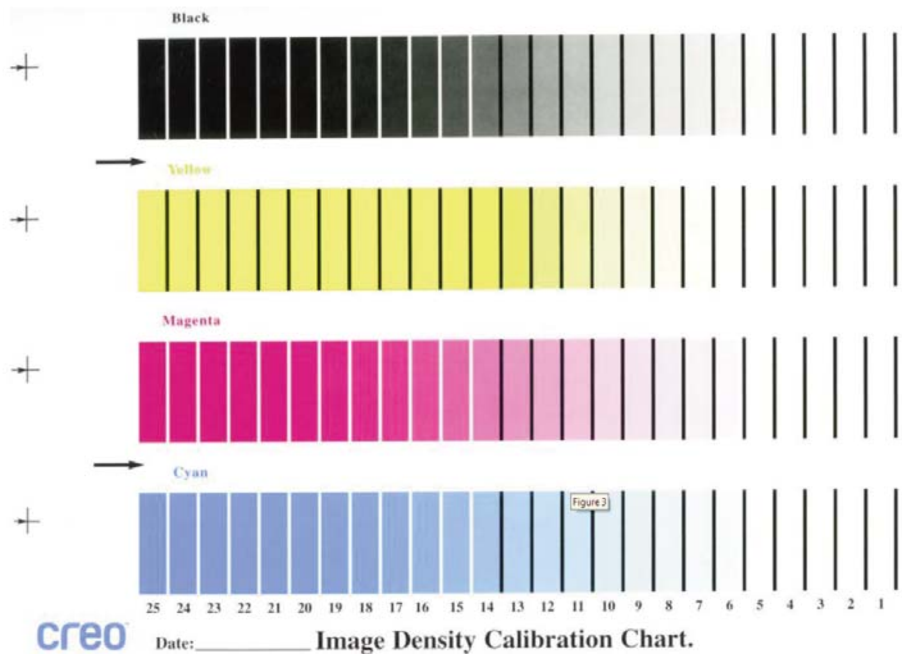

Figure 2: *CMYK Printer Calibration Chart (for Xerox DC-250)*

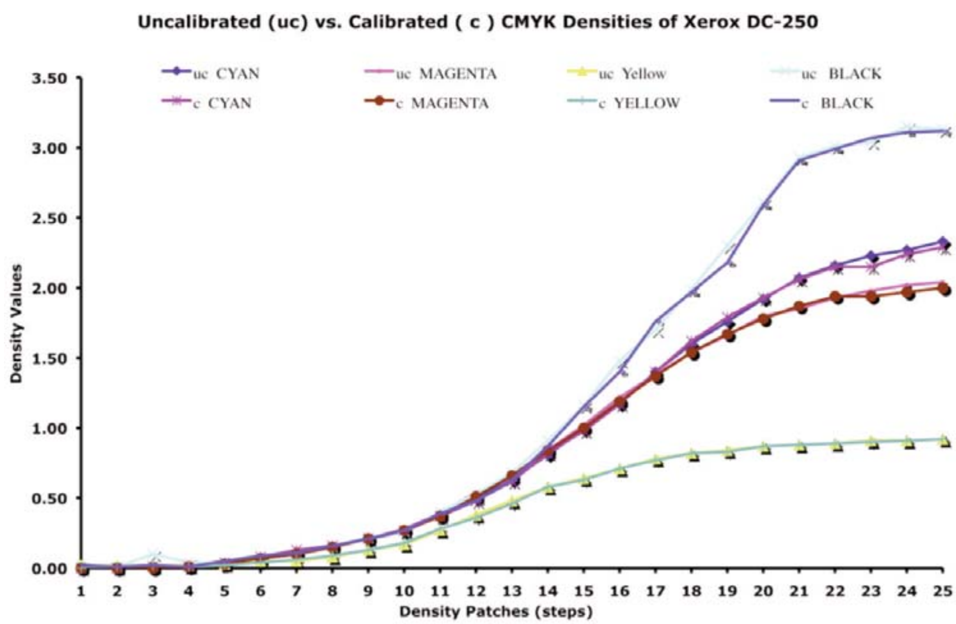

Figure 3: *Uncalibrated vs. Calibrated CMYK SID Curve*

4.2. Test Image for Printing

A one-page custom test image of 8.5” x 11” size was created for proofing and printing use for the experiment (see Figure 4). The test target contained the following elements: an ISO 12647-7 Control Strip, and CMYK & RGB tone-scales. Colorimetric data from solid colors (CMYK & RGB) were extracted from the tone-scale. Color management settings were disabled in Adobe InDesign CS-4 page layout application. All the image elements were imported into the page layout program and a PDF file was made without compressing the image data. The PDF file was sent to the Xerox DocuColor-250 Digital Press raster image processor (RIP). A total of 100 sheets were printed. The press front-end system is powered by CREO Spire cx250 RIP, which runs on a Windows XP platform (Dell Computer). Table 1 presents the variables, materials, conditions, and equipment associated with the scanner, monitor and printer of this experiment (see Table 1).

4.3. Printed Color Samples for the Analysis

A total of 100 prints (copies) were printed, on 80 LBS matte-coated paper (K = 5, n = 80, N = 100). Colorimetric data (L* a* b*) for various color quantification for each group was generated from the printed colors (solid CMYK & RGB colors) by using five different spectrophotometers (X-Rite DTP22, EyeOnePro, SpectroEye, X-Rite 528, and DatacColor SpyderPRINT) with various interface applications, such as the ColorShop X, MeasureTool, SpyderPrint, and SpotOnPress!

The sample size was selected in order of the specific confidence interval ($\alpha = 0.05$). A random sampling technique was used to identify the sample size because of the large size (N = 100) of the total population. After the printing, multiple devices were used to collect the colorimetric data from the sample. Glass, G.V. & Hopkins, K.D. (1996), provides an objective method to determine the sample size when the size of the total population is known. The total population for this study was 100 (N) printed sheets. The following formula was used to determine the required sample size, which were 80 (n) printed sheets for this study.

$$n = \chi 2\ NP\ (1-P)\ /\ d2\ (N-1) + \chi 2\ P\ (1-P)$$

where: n = the required sample size

$\chi 2$ = the table value of chi-square for 1 degree of freedom at the desired confidence level (3.84)

N = the total known population size

P = the population proportion that it is desired to estimate (.50)

d = the degree of accuracy expresses as a proportion ($\alpha = 0.05$)

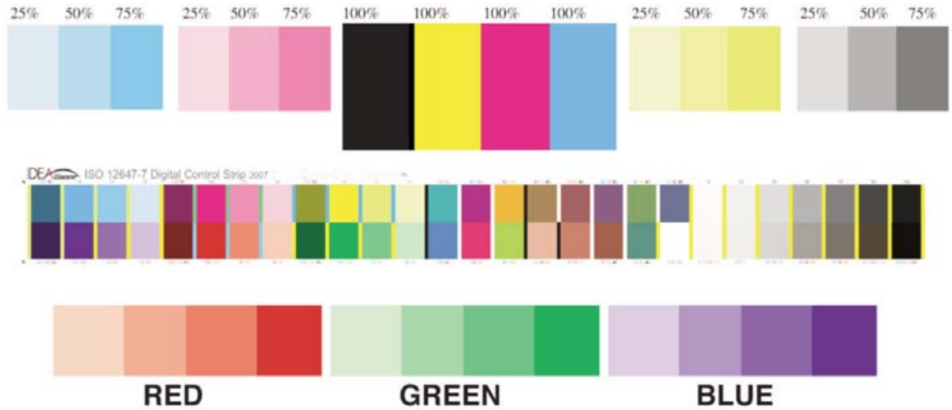

Figure 4: *Test Image for Printing/Color Analysis*

Randomly selected 80 printed samples were analyzed. Colorimetric data (L* a* b*) values of these 80 were measured by using a spectrophotometer (one type of device). Only solid colors of CMYK and RGB were measured. For each color of every sample measured the ΔE was derived by using the reference values vs. measured (or printed color) values. By using the ΔE values of all colors, an average ΔE was derived. The same procedures were applied for all five different types of devices.

Variable	Material/Condition/Equipment
Test Image	Custom Target
Control strips	ISO 12647-7, and SpotOn!Press
Image Editing Software	Adobe PhotoShop CS-5
Page Layout Software	Adobe InDesign CS-5
Source Profile (RGB)	Adobe 1998.icc
Emulation Profile (CMYK)	SpireOptimized.icc
Destination Profile (CMYK)	SpireDC250.icc
Color Management Module (CMM)	Adobe (ACE) CMM
Computer & Monitor	Apple Macintosh 10.5.8/LCD
Raster Image Processor (RIP)	Creo Spire x250
Printer	Xerox DocuColor-250 Color Laser
Uncalibrated CMYK SID	C = 1.71; M = 1.68; Y = 1.10; and K = 2.09
Calibrated CMYK SID	C = 1.19; M = 1.23; Y = 0.94; and K = 1.96
Screen Ruling	200 LPI
Print Resolution	2400 x 2400 DPI
Toner	Xerox Color Laser
Paper (sheetfed)	MOHAWK 80 LBS matte-coated
Type of Illumination/Viewing Condition	D50
Color Measurement Device(s)	X-Rite Eye-One-PRO Spectrophotometer, X-Rite DTP22, X-Rite 528 SpectroDensitometer, X-Rite Spectro-Eye, DataColor SpyderPRINT, and X-Rite DTP34 scanning densitomter
Data Collection/Analysis Software	ColorShop X, MeasureTool, SpyderPRINT, SpotOn! Press, and MS-Excel

Table 1

4.4. Statistical Method Applied for the Experiment Data Analysis

A Statistical Package for Social Sciences (SPSS) was used to analyze the average ΔE of all these five devices to determine the spectral response variation. Since the K = 5, a one-way Analysis of Variance (ANOVA) with equal n's method (at $\alpha = 0.05$) was used to determine the significant differences that exist between the (K = 5, n = 80, and N = 100) group means (averages) color deviations of the various instruments (Glass & Hopkins, 1996). The F-test can be calculated by using the following equation (Glass & Hopkins, 1996).

$$F = \frac{\sigma_b^2}{\sigma_w^2} = \frac{MS_b}{MS_w} = \frac{SS_b / V_b}{SS_w / V_w} = \frac{\sum n_k \left(\bar{X}_k - \bar{X}\right)^2 / K-1}{\sum \left(X_{ik} - \bar{X}_k\right)^2 / N-K} \qquad [3]$$

When statistically significant effects were detected among the five groups, the Tukey method - Post hoc ANOVA analysis was used to determine which group (K) means were significantly different. The Tukey method is also known as the honest significant difference (HSD) test between two sample means, can be determined by using the following equation (Glass & Hopkins, 1996). The F distribution and a probability value p, which is derived from the F, were used to determine if significant differences exist in spectral response variation of multiple devices. F is a ratio of two independent estimates of the variance of the sample, namely between the groups and within the groups (K = 5, N = 100). A low p value (or higher F value) is an indication that one should reject the stated null hypothesis (Ho) in favor of stated alternative hypotheses (Ha). It means one of the instrument means (average) is significantly different. It suggests that there is a strong support that at least one pair of the instrument means is not equal. The higher the p value (or lower F value) indicates that the means of various devices are not statistically different.

$$q_1 = \frac{\bar{X}_1 - \bar{X}_K}{S_{\bar{X}}} \qquad [4]$$

The value of q is the difference between the larger and smaller means of the two samples. Differences among the means at $p \leq 0.05$ were considered to be statistically significant among all the groups (K = 5) or multiple spectrophotometers. The main spectral response variation among the devices in a CMW was determined by using the above stated methods (F and q). The HSD multiple comparison test (with $\alpha = 0.05$) in the experiment enabled the researchers to identify the significant difference between one group to others. In other words, which instrument differs significantly from the other one?

5. Data Analysis and Research Findings

ANOVA method was used to analyze the collected data. Color difference (ΔE) was also derived to see the noticeable color differences that exist among the various instruments. As stated in the previous section, the digital color prints (or proofs) were analyzed by using various instruments against the reference data to determine the colorimetric deviations for ΔE average. Overall color reproduction of this experiment is associated with these colorimetric variations (COLVA) only, is the ΔE average.

Subjective judgment on color difference was not used (or applied) in this study. The subjective judgment of color difference could differ from person to person. For example, we see colors in an image not by isolating one or two colors at a time (Goodhard & Wilhelm, 2003), but by mentally processing contextual relationships between colors where the changes in lightness (value), hue, and chroma (saturation) contribute independently to the visual detection of spatial patterns in the image (Goodhard & Wilhelm, 2003). Instruments, such as colorimeters and spectrophotometers, could eliminate the subjective errors of color evaluation of people. In comparing the color differences between two colors, a higher (ΔE or ΔH) is an indication that there is more color difference and a lesser (ΔE or ΔH) is an indication of less color difference. Analyzed results are presented in the following section.

5.1. Average Color Deviation (ΔE): Reference Vs. Printed Colorimetry

ANOVA test shows that there is a significant difference among the average ΔE produced by each (multiple) instrument, $F(4, 395) = 10.58$, $p = 0.000$. Data indicates that each of the device measured colors differently. As such, the effect is significant at the $p < 0.05$ for all five spectrophotometers (see Table 2).

Post hoc analysis using the Tukey HSD criterion for significance among the multiple spectrophotometers deviation means (averages) indicated that when comparing Spectro-Eye device (1) with other devices (2, 3, 4, and 5), statistically there is a significant difference in the average ΔE produced by these various types of color measuring devices (see Table 3) at the $p \leq 0.05$. The Tukey HSD test also indicated that the mean score difference of device 1 ($M = 8.93$, and $SD = 0.378$) is significantly different than the other devices. The spectral response variation of this device one is higher. No significant difference was found among mean scores of devices 2, 3, 4, and 5 (EyeOne-Pro, X-Rite 528, X-Rite DTP22, and DataColor SpyderPrint).

Summary of ANOVA for Multiple Color Measuring Devices Influence on the Average ΔE

Source of Variation	*Sum of Square*	*df*	*Mean Square*	*F*	*Sig.*
Between Group	17.36	4	4.34	54.85	0.000*
Within Groups	6.73	395	0.08		
Total	24.09	399			

**Significant Difference [(α = 0.05 > 0.001) (F = 54.85 > 2.48)]*

Table 2

Comparison	*Mean Difference*	*SD Difference*	*Sig.*
1 vs. 2	1.027	0.145	0.000**
1 vs. 3	1.065	0.174	0.000**
1 vs. 4	1.096	0.157	0.000**
1 vs. 5	1.175	0.052	0.000**
2 vs. 3	0.038	0.029	0.994
2 vs. 4	0.069	0.012	0.946
2 vs. 5	0.148	0.003	0.513
3 vs. 4	0.031	0.007	0.997
3 vs. 5	0.110	0.002	0.767
4 vs. 5	0.078	0.005	0.915

** p ≤ 0.05 and ** p ≤ 0.001 (1 = Spectro-Eye, 2 = EyeOne-Pro, 3 = X-Rite 528, 4 = X-rite DTP22 and 5 = DataColorSpyderPrint)*

Table 3

6. Conclusions

The contents of this research report demonstrated the use of multiple spectrophotometers on the digital color output. The findings of this study represent specific printing or testing conditions. The images, printer, instrument, software, and paper that were used are important factors to consider when evaluating the results. The findings of the study cannot be generalized to other CMW. However, other graphic arts educators, industry professionals, and researchers may find this study meaningful and useful. For example, educators can implement the similar or presented model (or method) to teach color management modules. The colorimetric data of this experiment led to the conclusion that the selection of a device to measure the color is an important step in a CMW in order to evaluate colors more accurately.

The conclusions of this study are based upon an analysis of the spectral response variation by ANOVA test data and major findings (data and experience of the experiment). In this study, the established null-hypothesis (Ho) of the experiment was rejected, and the alternative hypothesis (Ha) was retained. The data from the ANOVA test revealed that there were significant differences in the spectral response to a color among the multiple devices. Average color deviation (ΔE) was significantly higher for the device one (X-Rite Spectro-Eye), when compared with other devices used in the experiment. Statistically, it was found that there was no significant difference among the remaining devices in the average color deviations (ΔE) produced by these devices.

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