Colorimetric Variation (COLVA) of ICC Color Rendering Intents (CRI) on the Digital Color Output in a Color Managed Workflow (CMW)

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Abstract

The purpose of this experiment was to determine the influence of applied ICC color rendering intents in the overall color reproduction in a Color Management Workflow (CMW). The experiment analyzed the application of four ICC-specified color rendering intents (absolute, perceptual, relative, and saturation intents) on the digital color output. The data contained in this report is the result of an experiment that was conducted to test an accepted color management practice to gain a greater understanding of the presumptions associated with the application of rendering intents.

The experiment examined the four ICC color rendering intents as independent groups (K = 4) using a one-way Analysis of Variance (ANOVA) with equal n's

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method (at α = 0.05) to determine the significant colorimetric variation (COLVA) between the (K = 4, n = 15, and N = 60) group means (averages) color deviations of these intents. With four rendering intents (groups, K = 4), a one-tailed, non-directional hypothesis was established. The conclusions of this study are based upon an analysis of the COLVA by ANOVA test data and associated findings. The data from the ANOVA revealed significant differences in the color deviation of the reproduction among the multiple ICC color rendering intents (CRI). The colorimetric data produced by the experiment suggests that selection of a rendering intent is an important activity in a CMW as it relates to obtaining accurate output colors for a desired use/purpose.

1 Introduction

Modern graphic communications has emerged from a craft-oriented field toward a color management science demanding greater color reproduction control between the devices used in the print and imaging industry. Managing and controlling color from the input device to multicolor output device is a major concern for the graphic communications and imaging industry. 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 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.

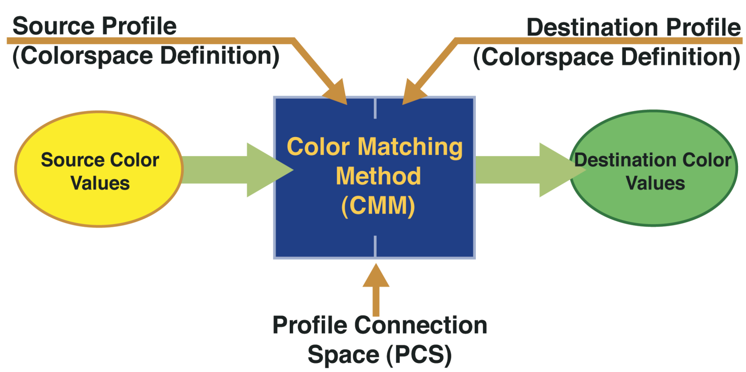

Figure 1. Schematic of PCS of CMS (Courtesy of Adobe Systems, Inc.).

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).

2.1 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.

2.2 ICC Color Rendering Intents

According to ICC, color gamut mapping can be completed by one of the four ICC recognized colorimetric rendering intents: perceptual, absolute, relative, and saturation. The rendering intent determines how the colors are processed that are present in the source gamut but out of gamut in the destination (output).

Rendering intents compiled by the ICC were "specifically defined for the purpose of cross-media reproduction using color management systems" (Marovic, Green, and MacDonald, 2002). In essence, intents are large look-up tables (LUT) that prescribe the range of RGB or CMYK values to an output device. Because the 16.7 million color choices (2^{24}) in an eight-bit color scheme (RGB mode) or 4.3 billion color choices (2^{32}) in CMYK mode are unmanageable, intents are employed. Each rendering intent tends to be associated with select types of images and/or workflow stages situations such as characteristics of the original, as well as reproduction media and its viewing conditions. These four intents—perceptual, saturation, absolute colorimetric and relative colorimetric—are intended to produce uniquely different results and thereby are often selected based on general use guidelines (Green, 2010).

Perceptual, also referred to as the photographic rending intent, is said to emphasize retention of relationship between colors; whereas colorimetric intents is thought to deliver high accuracy of in-gamut colors and saturation delivers more colorful images (Sharma, A. 2004). The aim of the perceptual rendering intent is generally to be pleasing, placing reproduction accuracy secondary while maintaining relationships between colors. This intent compresses or expands the gamut of the image to leverage attributes of the destination device. Colorimetric accuracy may be compromised (Marovic, et al. 2002).

Saturation rendering might be thought of as the vendor-specific intent, as this technique is most often used with graphics and text with little regard for color per se. By saturating the pixels in the image, hue and lightness is discounted. As with perceptual, this intent seeks to adjust for different devices, media and viewing conditions. Many suggest that it is suited most for images that incorporate charts and diagrams (Sharma, G. 2003).

Absolute rendering intent strives to create exact colors. It is used to predict how an image will appear when printed on a specific substrate. While colors that equate between the original and the print are unchanged, those out-of-gamut are clipped. With this intent, the reproduction will theoretically match the original if the paper matched. Proofing often uses this intent.

Relative colorimetric and absolute intents use clipping where a gamut boundary is forced. The relative colorimetric intent, however, relates to a white point on the substrate, best chromatically adapted to D50 conditions, and adjusts all colors maintaining their relative position to white. Where matches between reproduction and original are sought, this intent often serves as the default.

It may be said that ICC rendering intents invite a heuristic application to a subjective solution. In contrast, psychophysiology evaluation techniques (described by some as 'the total experience'), have informed findings about colorimetric rending methods (Milkovic, Knesaurek, Mrovac, and Bolanca, 2004) and gamut-mapping algorithms alike (Braun, Bala, and Harrigton, 2005). These techniques seek to quantify perceptible change in color, though studies find that while CIE describes ΔE of 1 as perceptible, the "average consumer would not detect any difference less than ΔE max value of 5" (Mason, 2007). The use of visual qualitative analysis has informed the selection of rendering intents and is commonly a metric incorporated into research about digital proofing (Lin and Zhou, 2009). Illustrative of the debate about generalizing intent usage, Green (2010) suggests that, "it is not possible to standardize re-purposing transforms" as they hinge on subjectivity and viewer preference. Furthermore, Green (2010) continues to states that the perceptual and saturation intents are more apropos to re-purposing—producing a reproduction on a second medium where viewing conditions might be quite different. Whereas, he suggests that the re-targeting—intention of matching a reproduction on a different media is more fitting for colorimetric rendering intents.

Further compounding the challenge for color managers is device "personality" (Sharma, A. 2005), which seeks to couple standardized transforming methods (ICC rendering intents) and gamut mapping to establish quality validation. Where gamut mapping applies a set of rules to produce the best color match, rendering intent works to maintain color accuracy while also remapping non-reproducible colors (Berns, 2000). To systematically control for variance, color managers use industry intents which modify the input data by applying linear and non-linear compression, and various cutting techniques, along with select algorithms in accordance with ICC standards (Milkovic, Bolanca, Mrvac, and Zjackie, 2006). In short, these intents take visual data from one source, mathematically manipulate this data based-on predetermined industry criterion, and direct that re-purposed data to a select output device. Efforts to control device variance are a technological juggernaut for managers, given the characteristic differences of RGB and CMYK, electronic manipulation and physical manipulation, respectively.

2.3 Colorimetry

A 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.

2.4 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).

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

where: X_n, Y_n, Z_n: Tristimulus Values of XYZ for 2 Standard Observer

2.5 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).

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

where: 1 = Color 1 and 2 = Color 2

3 Purpose of the Research

The experiment was conducted in a color managed workflow (CMW) to determine the colorimetric variation (COLVA) based on the statistical evaluation among the four ICC standard color rendering intents. It focused on the application of various color rendering intents to print color images 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 influence of applied color rendering intents in the average and maximum ΔE in a CMW. The following one-tailed non-directional hypothesis was established, because of the multiple rendering intents (groups, K = 4).

> H_o: There is no difference (or relationship) in the average and maximum ΔE of multiple color rendering intents, when comparing the printed colorimetry against the reference colorimetry.
>
> H_a: There is difference (or relationship) in the average and maximum ΔE of multiple color rendering intents, 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 (IT8.7/4, ISO300, and ISO12647-7) chosen for printing, desired rendering intent applied, 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

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 ICC rendering intents in a color managed workflow (CMW). ICC specified color rendering intents are Absolute Colorimetric (ACR) Rendering intent, Relative Colorimetric (RCR) Rendering intent, Saturation Rendering (SR) intent, and Perceptual Rendering (PR) intent. Each rendering intent in the experiment was considered as a group, noted by letter "K" (K = 4). Fifteen samples for each group were printed, noted by letter "n" (n = 15). For all the four groups, a total of 60 samples were printed, noted by letter "N" (N = 60). 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).

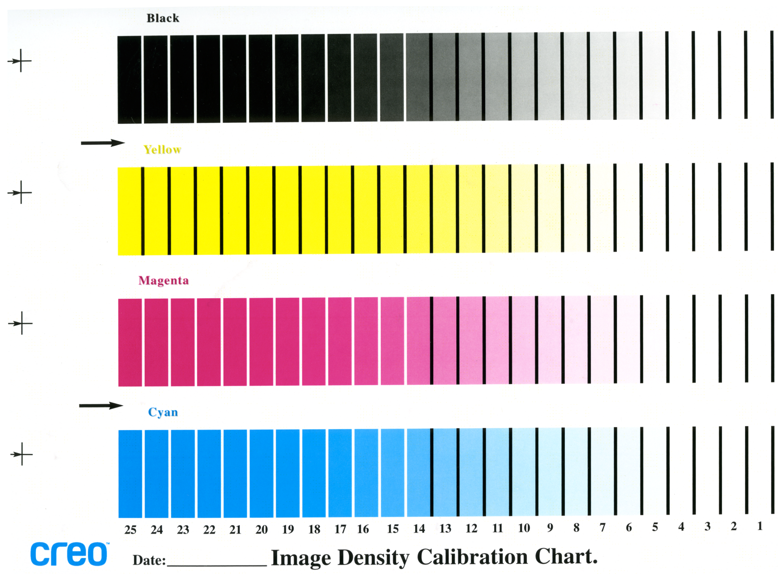

Figure 2. CMYK Printer Calibration Chart (for Xerox DC-250).

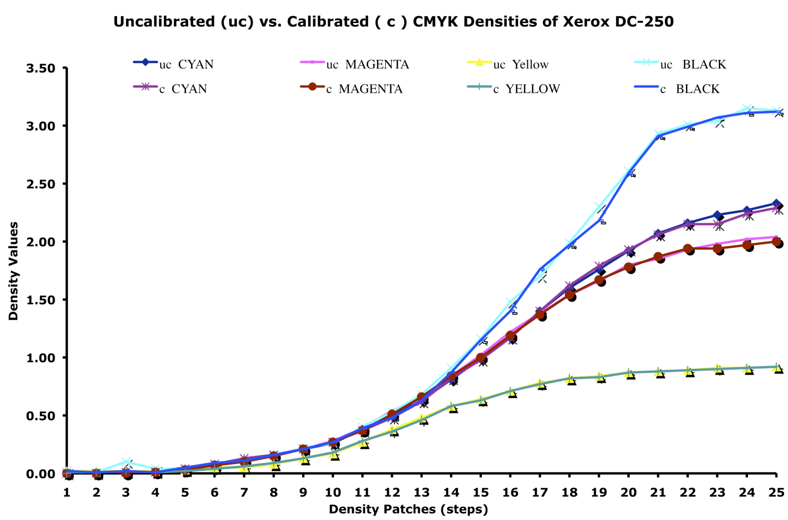

Figure 3. Uncalibrated vs. Calibrated CMYK SID Curve.

4.2 Test Image for Printing

A one-page custom test image (UW-Stout Test Image) of 12x18-in. size was created for proofing and printing use for the experiment (see Figure 5). The test target contained the following elements: an ISO300 and generic images for subjective evaluation of color, an ISO 12647-7 Control Strip, and SpotOnPress! Control strip. Colorimetric data was extracted from both the control strips. 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). The press front-end system is powered by CREO Spire cx250 RIP, which runs on a Windows XP platform (Dell Computer).

During the printing of the test image, in the color management option of the RIP, adjustments were made to print the test image with: a specific rendering intent, specific predefined (default) recommended profiles, LPI, and calibration data. In the CMYK emulation option of the RIP, adjustments were made to emulate the printing with a default profile and print the test image with various ICC rendering intents. A recommended predefined (default) destination profile was used to print the images. The device manufacturer recommended these two default profiles as predefined printing profiles. The final color printing/output is limited to these profiles and other image color adjustment techniques applied (rendering intents, LPI, and calibration curve, etc.).

4.3 Printed Color Samples for the Analysis

A total of 60 prints (copies) were printed, fifteen for each color rendering intent with the same image on 80 LBS matte-coated paper (K = 4, n = 15, N = 60). Colorimetric data for various color quantification for each group was generated from the printed colors *(SpotOn!™ and ISO 12647-7 control strips)* by using Eye-One-Pro spectrophotometer with interface applications, such as the SpotOnPress! and Fujifilm Taskero ColorPath Verified. Colorimetric data from SpotOn! was used to create the 2D gamut (profile) of the specific rendering intent. All the four-color rendering intent 2D gamuts were mapped for the visual comparison (see Figure 4).

Measured colorimetric data (via Fujifilm Taskero ColorPath Verified) from ISO 12647-7 control strip was used to determine the mean (average) and maximum color deviations between the printed colors and its reference data (IT8.7/4), such as: Average Delta E (ΔE), Maximum E. Average deviations of these attributes were mapped (bar chart) for the visual comparison (see Figure 6). Data derived from ISO 12647-7 control strip (sample) is the difference between the characterization data set (full IT8.7/4 target) and the sample. A total of 60 measurements were made, fifteen for each color rendering intent (K = 4, n = 15, N = 60). The IDEAlliance ISO12647-7 control strip contains only a small subsample of IT8.7/4 target. It contains too few patches to prove an accurate match to a specific industry standard. However, it does contain enough patches to monitor the accuracy of a color reproduction system against a reference target, such as the IT8.7/4. Table 1 presents the variables, materials, conditions, and equipment associated with the scanner, monitor and printer of this experiment (see Table 1).

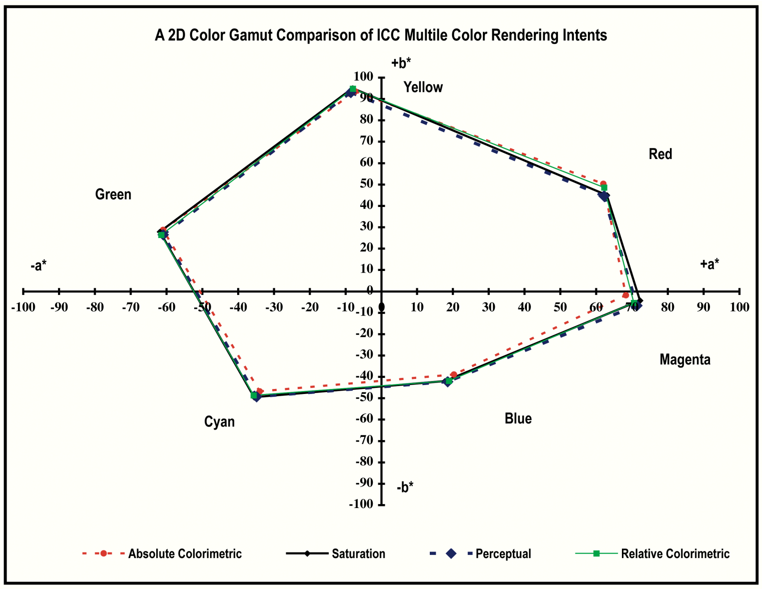

Figure 4. A 2D Gamut Comparison of multiple CRI's.

Figure 5. Test Image for Printing.

Table 1. Experimental and Controlled Variables

Variable	Material/Condition/Equipment
Test Images	UW-Stout Test Target
Control strips	ISO 12647-7, and SpotOn!Press
Profiling Software	X-Rite ProfileMaker 5.0.10
Profile Inspection Software	Chromix ColorThink-Pro 3.0 & Apple ColorSync
Image Editing Software	Adobe PhotoShop CS-4
Page Layout Software	Adobe InDesign CS-4
Source Profile (RGB)	Adobe 1998.icc
Emulation Profile (CMYK)	SpireOptimized.icc
Destination Profile (CMYK)	SpireDC250.icc
Color Management Module (CMM)	Adobe (ACE) CMM
Rendering Intents	ACR, RCR, PR, and SR
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	2400x2400 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 with Status T, 2

	angle, and X-Rite DTP34 scanning densitometer
Data Collection/Analysis Software	FUJIFILM ColorPath Verified, SpotOn! Press, and MS-Excel

4.4 Statistical Method Applied for the Experiment Data Analysis

Statistical Package for Social Sciences (SPSS) was used to analyze the collected data to determine the colorimetric variation (COLVA). Since the K = 4, 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 = 4, n = 15, and N = 60) group means (averages) color deviations of the various color rendering intents (Glass & Hopkins, 1996). The F-test can be calculated by using the following equation (Glass & Hopkins, 1996).

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

When statistically significant effects were detected among the four 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 the output color attributes of multiple color renderings intents. *F* is a ratio of two independent estimates of the variance of the sample, namely between the groups and within the groups (K = 4, N = 60). A low *p* value (or higher *F* value) is an indication that one should reject the stated null hypothesis (H_o) in favor of stated alternative hypotheses (H_a). It means one of the rendering intent means (average) is significantly different. It suggests that there is a strong support that at least one pair of the rendering intent means is not equal. The higher the *p* value (or lower *F* value) indicates that the means of various color attributes of the color rendering intents are not statistically different.

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

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 = 4) or color rendering intents. The main effect of the color rendering intents on the digital color output 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 color rendering intent 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 rendering intents. As stated in the previous section, the digital color prints (or proofs) printed with various rendering intents were analyzed by using ColorPath Verified against the IT8.7/4 reference data to determine the colorimetric deviations for ΔE average and ΔE maximum. Overall color reproduction of this experiment is associated with these colorimetric variations (COLVA) only ΔE average and ΔE maximum (see Figure 6).

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. ICC specified color rendering intents are Absolute Colorimetric (ACR) Rendering intent, Relative Colorimetric (RCR) Rendering intent, Saturation Rendering (SR) intent, and Perceptual Rendering (PR) intent. Analyzed results of influence of these color rendering intents on the color output are presented in the following section.

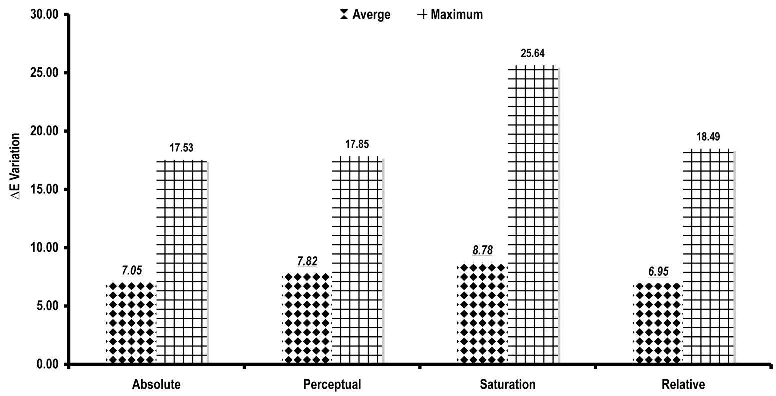

Figure 6. COLVA of Multiple Color Rendering Intents.

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) color rendering intent, $F (3, 56) = 10.58, p = 0.000.$ Data indicates that each of the rendering intents altered the printed image colors differently. As such, the effect is significant at the $p < 0.05$ for all four rendering intents (see Table 2).

Post hoc analysis using the Tukey HSD criterion for significance among the multiple color rendering intents means (averages) indicated that when comparing saturation rendering intents (1) with other rendering intents (2, 3, and 4), statistically there is a significant difference in the average ΔE produced by various color rendering intents (see Table 3) at the $p \leq 0.05$. The Tukey HSD test also indicated that the mean score difference of rendering intent 1 (M = 8.78, and SD = 0.89) is significantly different than the rendering intents, 2 (M = 7.82, SD = 0.64), 3 (M = 7.05, SD = 1.15), and 4 (6.95, SD = 1.23). The saturation rendering intent resulted in producing the highest average ΔE, while the relative rendering intent produced the lowest. No significant difference was found among mean scores of rendering intents 2, 3, and 4 (perceptual, absolute, and relative).

Table 2. Summary of ANOVA for Multiple CRI Influence on the Average ΔE.

Source of Variation	*Sum of Square*	*df*	*Mean Square*	*F*	*Sig.*
Between Group	32.24	3	10.75	10.58	0.000*
Within Groups	56.89	56	1.02		
Total	89.13	59			

** Significant Difference [(α = 0.05 > 0.001) (F = 10.58 > 2.77)]*

Table 3. Tukey HSD Multiple Comparison Multiple CRI Influence on the Average ΔE.

Comparison	*Mean Difference*	*SD Difference*	*Sig.*
1 vs. 2	1.122	0.191	0.019*
1 vs. 3	1.732	0.261	0.000**
1 vs. 4	1.824	0.338	0.000**
2 vs. 3	0.609	0.452	0.365
2 vs. 4	0.701	0.529	0.245
3 vs. 4	0.092	0.077	0.995

* $p \leq 0.05$; ** $p \leq 0.001$ *(1 = Saturation, 2 = Perceptual, 3 = Absolute, and 4 = Relative)*

5.2 Maximum Color Deviation (ΔE): Reference Vs. Printed Colorimetry

ANOVA test shows that there is a significant difference among the maximum ΔE produced by each (multiple) color rendering intent, $F(3, 56) = 16.99$, $p = 0.000$. Data indicates that each of the rendering intents altered the printed image colors differently, as such the effect is significant at the $p \leq 0.05$ for all four rendering intents (see Table 4).

Post hoc analysis using Tukey HSD criterion for significance among the multiple color rendering intents means (averages) indicated that when comparing saturation rendering intent (1) with other rendering intents (2, 3, and 4), statistically there is a significant difference in the maximum ΔE produced by various color rendering intents (see Table 5) at the $p < 0.05$. Tukey HSD test also indicated that the mean score of rendering intent 1 (M = 25.64, and SD = 3.07) is significantly different than the rendering intents 2 (M = 18.49, SD = 5.12), 3 (M = 17.84, SD = 1.76), and 4 (17.53, SD = 3.72). The saturation rendering intent resulted in producing the highest maximum ΔE, while absolute rendering intent produced the lowest. No significant difference was found among mean scores of rendering intents 2, 3, and 4 (perceptual, absolute, and relative).

Table 4. Summary of ANOVA for Multiple CRI Influence on the Maximum ΔE.

Source of Variation	*Sum of Square*	*df*	*Mean Square*	*F*	*Sig.*
Between Group	671.47	3	223.82	16.99	0.000*
Within Groups	737.84	56	13.18		
Total	1409.31	59			

**Significant Difference [(α = 0.05 > 0.001) (F = 16.99 > 2.77)]*

Table 5. Tukey HSD Multiple Comparison Multiple CRI Influence on the Maximum ΔE.

Comparison	*Mean Difference*	*SD Difference*	*Sig.*
1 vs. 2	7.148	2.047	0.000**
1 vs. 3	7.796	1.314	0.000**
1 vs. 4	8.108	0.645	0.000**
2 vs. 3	0.647	3.361	0.961
2 vs. 4	0.959	1.402	0.887
3 vs. 4	0.312	1.959	0.995

* $p \leq 0.05$; ** $p \leq 0.001$ *(1 = Saturation, 2 = Relative, 3 = Perceptual, and 4 = Absolute)*

6 Conclusions

The contents of this research report demonstrated the complete COLVA of ICC multiple color rendering intents 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 module. The colorimetric data of this experiment led to the conclusion that the selection of a rendering intent of a choice is an important step in a CMW in order to output accurate colors of choice for a desired use/purpose.

The conclusions of this study are based upon an analysis of the COLVA by ANOVA test data and major findings (data and experience of the experiment). In this study, the established null-hypothesis (H_o) of the experiment was rejected, and the alternative hypothesis (H_a) was retained. The data from the ANOVA test revealed that there were significant differences in the color reproduction among the multiple ICC color rendering intents (CRI). Average color deviation (ΔE) and maximum color deviations (ΔE) were significantly higher for the saturation rendering intent, when compared with other color rendering intents (the absolute, relative, and perceptual rendering intents). Statistically, it was found that there was no significant difference among the remaining CRI in the average and maximum color deviations (ΔE) produced by these CRI.

Additionally, the experiment experience and analyzed data proves that there were no color differences among the printed samples (photographs, commercial, and digital printing) of rendering intents, such as the absolute, relative, and perceptual. Furthermore, one could achieve the same color output regardless of which rendering intent was used among the three (absolute, perceptual, and relative colorimetric rendering intents). However, one should be cautioned to use the saturation intent because this intent produced the highest color deviation when compared with other intents. Higher color deviations (ΔE or ΔH) means that the printed colors could be out of established deviation tolerances. Numerous reports reveal that the saturation intent was the least used in the industry, as it merely tries to produce good colors without any concern for the color accuracy.

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