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Print-to-Proof Visual Match Using Papers with Optical Brightening Agents

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Abstract

Optical Brightening Agents (OBAs) are chemicals added to paper pulp whose purpose is to brighten the white point of the paper. Adding OBAs results in a brighter white, increased tonal range, and more chromatic colors. However, adding OBAs can also create problems in visual print-to-proof match where proofing substrates do not contain OBAs. Visual print-to-proof match is the final judge of conformance in a print business. When printing and proofing in conformance to standards and specifications on non-OBA papers, there is visual match between the print and the proof. Printing on OBA loaded papers causes two main problems: (1) difficulty in achieving conformance to printing standards and (2) visual print-to-proof mismatch. To solve the above problems, this research begins by adopting the new “M1” measurement condition and the revised ISO 3664:2009 viewing conditions. It then assumes that the print on OBA loaded paper is the anchor and the proof must be color managed to match the print using these new measurement and viewing conditions.

In order to test the proposed solution, the researcher prepared a series of prints and proofs that (1) reproduced the proof-to-print match traditionally achieved on non-OBA loaded printing papers (the anchor pair), (2) reproduced the proof-to-print mismatch on OBA loaded printing papers (the problem pair),

and (3) tested the color managed approach to solving the problem described above (the solution pair). Finally, these pairs were evaluated by a panel of observers in a paired comparison experiment under the revised ISO 3664:2009 viewing conditions.

The results of the paired comparison experiment first demonstrated that the researcher could reproduced both a proof-to-print match on non-OBA loaded papers and a proof-to-print mismatch on OBA loaded papers. In addition, the solution pair was demonstrated to be preferred to all other pairs at the .05 level of significance. Finally CIELAB plots of the problem pair and the solution pair under M1 conditions supported the results of the pair comparison experiment. Under M1 conditions the proof-to-print mismatch (difference in CIELAB values) for the problem pair was shown to be approximately twice as large as the proof-to-print mismatch for the solution pair.

Based on the results of this research, the proposed solution was shown to be a promising approach for solving the industry wide problem of print-to-proof mismatch when printers print on OBA loaded papers

Chapter 1

Introduction

Statement of the Problem

International graphic technology standards, such as ISO 12647-2 for lithographic offset printing and ISO 12647-7 for digital proofing, define quantifiable, practical, and achievable aims and tolerances defined colorimetrically for the printing and publishing industry. These parameters assure color repeatability and provide an effective way of communicating within the printing reproduction workflow (i.e. copy preparation, proofing, printing, and finishing processes). ISO 12647-2 recommends five types of papers that do not contain Optical Brightening Agents (OBAs). The use of OBAs provides advantages, such as increasing the paper brightness and giving the perception of increased whiteness. Printing on OBA loaded paper allows images to have increased chromaticity and saturation compared to printing the same images on non-OBA papers.

Optical Brightening Agents work by absorbing UV energy and re-emitting it as light in the blue region of the spectrum. OBAs make the white point of the paper bluer, increasing -b* values, and the addition of this blue light is perceived as “brighter.” The white point of the papers defined in Table 1 in ISO 12647-

2:2004 are characteristic of non-OBA papers. For instance, gloss-coated paper has aims of L*=95, a*=0, and b*= -2, whereas highly OBA loaded paper could have b* values up to -10 and reflectance at certain wavelengths higher than 100%. Printing on highly OBA loaded paper will therefore not conform to ISO 12647-2 paper's white point specifications. Because the offset lithographic printing process uses transparent inks, the bluish re-emitted light due OBAs, will influence the printed colors.

ISO 12647-7 was developed to produce proofs that visually match production prints according ISO 12647-2. When production paper cannot be used in proofing (due incompatibility with the proofing system) or when production paper is unknown, the proof will simulate the dataset's white point. If the printing paper contains OBAs, the proof's white point will be different than the print's white point. As a consequence of this white point difference, the print's overall color and appearance will differ from the color and appearance of the proof. This color difference leads to a second problem: print-to-proof visual mismatch.

Visual match between print and proof is important because print buyers accept a printed job based on the appearance and similarity of the printed reproduction to the contract proof. Therefore, print-to-proof match is expected and implied in the printing and publishing industry. When printing and proofing conform to accepted international standards, yet, print and proof do not match, there is a problem with meeting the customers' expectations. Because the addition of OBAs is a recent trend in the paper industry, traditional Color Management Systems (CMS) have not solved the two problems associated with the use of OBAs in printing papers: non-conformance to standards, and achieving an acceptable visual match. The industry has recognized this problem and has revised viewing and measurement standards to allow better visual print-to-proof match. Nevertheless, implementation of these two critical international standards has been slowed by the late arrival of M1 spectrophotometers. As a result, the fully potential of these two standards to enable a solution to the problem of OBA loaded papers has not been tested under actual printing conditions. Thus the problem addressed by this research is to test the capability of this new technology coupled with a new proofing approach to improve visual print-to-proof match.

Reason for Interest

Printing and proofing on OBA papers represent a real and current problem in the graphic arts industry. On the other hand, it presents an opportunity because there are possible solutions, as mentioned earlier, to the OBA issue in the market. Using a scientific approach, we can put together a research framework, followed by experiments, data collection, and observations to test the hypotheses.

The researcher has a number of reasons to be personally interested in this project. By studying and conducting research about this subject, the researcher will learn and gain experience in color management and printing standards implementation. The research will develop the researcher's ability to conduct and manage a project which provides real-world solutions for the industry. In addition, the research findings may be published in industry journals, which will result in industry recognition for the researcher and RIT. Finally, the experience gained will further develop the researcher's problem-solving skills, which will help position him in the market as a color management and printing standards expert.

Chapter 2

Theoretical Basis

Metamerism

Color is a perception which occurs in the brain of the observer. Nevertheless, in order to perceive color, there must be a light source, an object that modifies the light, and an observer whose brain perceives as color the light modified by the object (Billmeyer and Saltzman, 1981). The concept of trichromacy was created to capture the interaction between a light source, an object, and an observer (Berns, 2000).

If two objects have the same spectral reflectance, the perceived color will be the same despite the lighting conditions and observer. This invariant match is called a “spectral match”; the visual response is always the same (Berns, 2000).

Color reproduction is possible because stimuli do not need to have identical spectral properties to match in color. For instance, using three or four primaries (RGB or CMYK) the human perceptible color gamut is reproducible through television, photography, and printing (Berns, 2000). This kind of match, when two spectrally different stimuli produce the same visual response, is called a “metameric” or “conditional” match. This kind of match does depend on the lighting condition and observer. For a metameric match, if the lighting condition or observer changes, the perceived color may change.

This research is based on the concept of a metameric match. In this research, a print on OBA loaded paper is compared to a proof prepared on non-OBA paper. If there is a color match under these conditions, it will necessarily be a metameric match. In addition to judging the quality of match through observation, a color difference metric can be used to quantify the extent to which the two stimuli differ one from the other.

Color Difference Metrics

In 1976 the CIE developed CIELAB, a transformation of the 1931 XYZ color space, with the purpose of modeling color in a more uniform space. Although this transformation improved the uniformity of the resulting color space, the new space was still not completely uniform (Johnson and Green, 1999). A color difference metric named ΔE^*_{ab} was created to describe the difference between two colors in the CIELAB color space. The deficiency of this metric is that it ignores the fact that human color vision is more sensitive to color differences in some parts of or along certain dimensions of color space than it is in others. As a result, pairs of colors with equal ΔE^*_{ab} color differences are perceived to have unequal visual differences (Berns, 2000).

Instead of coming up with a more uniform color space to address this deficiency, color scientists used the CIELAB color space and modified the color difference formula to get a more consistent result when compared to visual color judgments (Johnson and Green, 1999.) The ΔE^*_{ab} metric was revised several times leading to new color difference metrics: ΔE_{94}, ΔE_{cmc}, and ΔE_{00}. Luo, Cui and Rigg (2000) tested ΔE_{00} together with the other CIELAB based equations. They found that ΔE_{00} color difference equation outperformed ΔE_{94} and ΔE_{cmc} "by a considerable margin" and has been published as "an improvement to industrial color-difference evaluation". Habekost (2007) also found that ΔE_{00} relates well to the human perception of color differences.

ISO Technical Committee 130 (TC130) has a mandate that CIE ΔE_{00} shall be used in all new printing standards as well as printing standards to be revised when appropriate. As such, ISO/DIS 15339-1 specifies color tolerance in terms of ΔE_{00}. This research adopts ΔE_{00} in the data analysis phase with the use of macros in Excel. The ΔE_{00} calculation is shown below in a step-by-step process (Luo, Cui, and Rigg, 2000):

Step 1. Calculate CIE L*, a*, b* and C*:

$$
\begin{aligned}
L^* &= 116 f\left(Y/Y_n\right) - 16 \\
a^* &= 500\left[f\left(X/X_n\right) - f(Y/Y_n)\right] \\
b^* &= 200\left[f(Y/Y_n) - f(Z/Z_n)\right] \\
C^*_{ab} &= \sqrt{a^{*2} + b^{*2}}
\end{aligned}
$$

where

$$
f(I) = \begin{cases} I^{1/3} for I > 0.008856 \\ f(I) = 7.7871 + 16/116 ... Otherwise \end{cases}
$$

Step 2. Calculate a', C', and h':

$$L' = L^*$$
$$a' = (1+G)a^*$$
$$b' = b^*$$
$$C' = \sqrt{a'^2 + b'^2}$$
$$h' = \tan^{-1}(b'/a')$$

where

$$G = 0.5\left(1 - \sqrt{\frac{\overline{C^*_{ab}}^7}{\overline{C^*_{ab}}^7 + 25^7}}\right)$$

Step 3. Calculate ΔL', ΔC', and ΔH'.

$$\Delta L' = L'_b - L'_s$$
$$\Delta C' = C'_b - C'_s$$
$$\Delta H' = 2\sqrt{C'_b C'_s}\sin\left(\frac{\Delta h'}{2}\right)$$

where

$$\Delta h' = h'_b - h'_s$$

Step 4. Calculate ΔE_{00}.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)}$$

where

$$S_L = 1 + \frac{0.015\left(\overline{L'} - 50\right)^2}{\sqrt{20 + \left(\overline{L'} - 50\right)^2}}$$

and

$$S_C = 1 + 0.045\overline{C'}$$

and

$$S_H = 1 + 0.015\overline{C'}T$$

where

$$T = 1 - 0.17\cos(\overline{h'} - 30^o) + 0.24\cos(2\overline{h'}) + 0.32\cos(3\overline{h'} + 6^o) - 0.20\cos(4\overline{h'} - 63^o)$$

and

$$R_T = -\sin(2\Delta\theta)R_C$$

where

$$\Delta\theta = 30\exp\left\{-\left[\left(\overline{h'} - 275^o\right)/25\right]^2\right\}$$

and

$$R_C = 2\sqrt{\frac{\overline{C'}^2}{\overline{C'}^2 + 25^7}}$$

ISO 15339-1 specifies color tolerances in terms of ΔE_{00}. This research implements ΔE_{00} for color difference calculations with the use of macros within the Microsoft Excel application.

Chapter 3

A Review of the Literature in the Field

Overview

The following sections summarize the literature reviewed regarding print-to-proof visual match using paper with optical brighteners. First, the importance of proofing in the graphic arts industry and the currently used printing and proofing standards are reviewed. Second, OBAs are explained, and how their use has compromised visual print-to-proof match when using current standards. The metameric nature of matching OBA prints with non-OBA proofs insures that a visual match depends on the viewing and measurement conditions. Finally, to restore visual print-to-proof match, viewing and measurement standards were revised to take into account the metameric nature of the match and the effect of OBAs on production paper's white point and resulting printed colors.

Traditional Print-to-proof Match

As part of the graphic arts workflow, before a printer produces a job on press (e.g. using offset lithography), a proof is made, according to ISO 12647-7. The proof simulates the visual characteristics of the final production print. Proofs show the customer and printer how the job will look after printing, so it is possible to make changes to the design before production (Bruno, 1986). When the customer approves the proof, it becomes the reference, meaning that the print has to be able to match the proof. Before the existence of digitally color-managed workflows, proofs were also used as a visual reference to monitor and control the color reproduction process (Liang, 1994).

A proofing system consists of the hardware (combination of output device-substrate-ink) and software used to create proofs. Proofing can be made in two ways: 1) using monitors and displays which is know as softproofing, and 2) as tangible images consisting of colorants on a substrate which is known as hardcopy proofing (Field, 1999). This research is focused on hardcopy proofing systems.

The first proofing standard was the 1993 SWOP Booklet, which described film preparation, paper and ink requirements, and numerical dot gain specification for press proofing (Long, 1995). Today, ISO 12647-7:2007 is the standard most frequently used to specify the requirements (aims and tolerances) for a digital proofing system when it simulates a specific printing condition through a characterization dataset.

A characterization dataset establishes the relationship between CMKY values and the printed color (expressed in CIELAB or CIEXYZ values). If two printing processes are calibrated to the same characterization dataset (making the printable color gamut the same), different CMKY values will produce the same perceived color between the two processes (McDowell, 2002). This is the application of metamerism that makes color proofing possible.

Regarding offset lithography, ISO 12647-2:2007 specifies, among others, the following parameters: tone-value increase (TVI) and colorimetric values for process color solids; and recommends the substrate's CIELAB values, ISO brightness and mass per area. To achieve print-to-proof match, both processes, printing and proofing, shall be aimed to match the same characterization dataset. The dataset for offset lithography, Fogra39 was developed when printing papers did not contain optical brightening agents. Therefore, ISO 12647-2 for printing, ISO 12647-7 for proofing, and the Fogra39 dataset are based on non-OBA papers.

Print-to-proof agreement can be assessed by printing solid colors using printing and proofing technologies and computing a color differences between the resulting prints. However, print-to-proof agreement is generally judged using pictorial images where colorimetry is not applicable. In this case, subjective visual comparison of complex-pictorial images by a panel of observers is required, where variation from observer to observer might exist (Chung and Shimamura, 2001). To discriminate for anomalous trichromats and colorblind people, the D&H Color Rule (Pobboravsky, 1988) or the Farnsworth-Munsell 100 Hue Test should be applied to each observer. Standardized images, such as ISO SCID and Roman 16, should be used for visual comparisons.

Visual print-to-proof match is important because print buyers accept or reject jobs based on the appearance of the contract proof and its quality of visual match with the print. Therefore, print-to-proof visual match is expected in the printing and publishing industry. To achieve conformance to standards, and ultimately, print-to-proof visual match, a color-managed workflow must be implemented (Shimamura, Chung and Sigg, 2001).

Because producing a proof on a production press is expensive and time consuming (Bruno, 1986), printers use a less expensive and more flexible form of image recording technology (e.g. inkjet printing driven by a computer system) to produce the proof (Field, 1999). Therefore, the colorants, substrates and printing technology and conditions used in the off-press proofing system and the production process, will not be the same (Sidles, 2005). This type of color matching between proof and print relies on metamerism because images are produced using different colorants on different substrates (Chung and Shimamura, 2001).

As stated in the Theoretical Basis, a metameric match depends on viewing conditions and measurement. The graphic art industry uses ISO 3664 and ISO 13655 to specify viewing and measurement conditions respectively. When the printing (ISO 12647-2) and proofing (ISO 12647-7) standards were developed –around 2004, the necessity of controlling the UV part of the spectrum was not critical. Therefore, around 2004, viewing booths complied with ISO 3664:2000 and measurement instruments with ISO 13655:1996 M0/M2 (the instrument's light source closely matches Illuminant A/UV-Cut respectively). Since UV was invisible to the observer and papers did not interact with UV to produce visible light, both lighting bulbs and instrument lighting sources had ample or arbitrary tolerances in the UV region.

Optical Brightening Agents

The electromagnetic spectrum refers to the full range of energies (wavelengths) that photons have as they travel through space and time. The visible spectrum (i.e. light) ranges from 380-700 nm (Fraser, 2005). Optical Brightening Agents (OBAs) are chemicals added as fillers in the pulp preparation process that work by absorbing energy in the ultra violet spectrum (300-410 nm) and re-emit light in the blue (430-440 nm) area of the visible spectrum. In other words, OBAs are bluing agents. The result is an increase in whiteness and brightness that makes the paper more appealing to the print buyer (Kunz, 2008). Printing on brighter substrates has the advantage that the perceived printed colors look more saturated. OBAs also have the ability to hide imperfections in the paper.

Fillers are added because they are cheaper than pulp. Since optical brightening agents are more cost effective than non-fluorescent whitening agents (e.g. titanium dioxide, TiO_2) in achieving a given level of whiteness, the use of OBAs in production printing papers has become pervasive in the industry (NAPL, 2011). Highly OBA loaded papers are advertised as “the-best-of-the best” (Sappi, 2012), while even environmental friendly non-OBA loaded papers are experiencing a lack of sales. For instance, Sappi, one of the biggest paper manufacturers, has withdrawn its OBA-free grade, called "Lustro", advertising Opus-30 instead (Sappi, 2012).

Visual Print-to-proof Mismatch

One of the major problems associated with color accurate printing and print-to-proof match is the use of OBAs. The color of the printing substrate is a critical factor of the color appearance of a printed image because paper is the "fifth color" (ISO/DIS 15339-1). In the PSA printing standards survey, Chung (2011) found that the two most problematic technical issues for printing companies were that press sheet and proof do not match each other visually, and that paper containing OBAs does not conform to the paper white point specified in the international standard ISO 12647-2:2004.

If platemaking, proofing and printing are calibrated, and the ink and paper conform to current ISO standards, the printed production will visually match the proof (Chung, 2011). When proofing and printing substrates are not equal, or production paper does not conform to standards due to OBAs, the brightening agents will influence the production substrate's white point and the printed colors on it (Chung and Tian, 2011). In this case, conformance to current standards (i.e. ISO 12647-2) and visual proof-to-print match will be compromised.

Accounting for the Effect of OBAs

ISO Printing Standards

The International Organization for Standardization (ISO) is a federation of national standards bodies which works through Technical Committees (TC). ISO develops accredited standards which are recognized worldwide. The ISO Technical Committee for printing was formed in 1971 in France as TC130, Graphic Technology, and focuses on terminology, paper sizes, correction marks and typographical measurements. It was not until 1979 with the introduction of Color Electronic Prepress Systems (CEPS) that standards became mandatory (McDowell, 1996).

In addition to TC130, industry standards such as Specification for Web Offset Publication (SWOP), General Requirements for the Applications in Commercial Offset Lithography (GRACoL), and the Fogra 39 characterization dataset have been developed by industry associations (IDEAlliance, FOGRA, UGRA, etc.).

As stated in the previous section, most production papers are bluer (meaning that have a greater –b*) than the white point of papers in ISO 12647-2 due to their OBA content. The aims and tolerances specified in ISO 12647-2 assume printing on non-OBA paper. Hence, ISO 12647-2 is no longer representative of real-world production conditions.

ISO/DIS 15339-1 overcomes this limitation of ISO 12647-2 because it allows the characterization dataset to be adjusted relative to the production paper. Process control and digital color management allow printers to print by the numbers. Print by numbers means that the printer no longer prints to match a proof. Instead, he or she prints to match a dataset. Hence, the proof has to be prepared to match the print. The Fogra39 characterization data set can be adjusted to the production paper's white point, and these printing aims can be used as the proofing aims. If the dataset values match within a given tolerance, then a visual match is expected even if the white point of the print containing OBA is brighter than the withe point of the proof. To have a better perceptual correlation, ISO/DIS 15339-1 uses ΔE_{00} instead of ΔE^*_{ab} to express color differences.

Restoring Visual Print-to-proof Match

Viewing and measurement conditions must be aligned in order to achieve the match between non-OBA proofs and OBA prints. Because OBAs interact with UV energy, it is important to control that part of the spectrum, especially in viewing environments and measurement instruments. Printing experts were aware of this, so in 2004 technical committees initiated the effort to revise ISO 3664 and ISO 13655 simultaneously. The resulting revisions were published in 2009. The two documents were revised together because it was recognized that they form a system. As a result, the UV energy tolerances in D50 viewing booths were tightened and the light sources of measurement instruments were aligned to this viewing condition. The result was a new measurement condition known as M1, namely, CIE Illuminant D50 with specified UV energy. The following section summarizes these viewing and measurement conditions.

Measurement and Viewing Standards

ISO 13655:2009, among others, defines the following measurement conditions as a function of its light source:

- M0: instrument's illumination source to closely match illuminant A (2856^{o}K). The amount of UV radiation (i.e. wavelengths from 360-400 nm) is arbitrary.
- M1: instrument's illumination source to closely match illuminant D50. The amount of UV radiation is known.
- M2: the instrument's illumination shall contain radiation power in the wavelength above 400 nm. Before radiation impinges on the specimen, it should pass through a UV-cut filter.
- M3: the same illuminant as M2 with a polarization filter.

In addition, ISO 13655:2009 specifies that the instrument shall be 0/45 or 45/0 geometry. For the graphic arts, the observer should be 2^o at CIE D50 illumination.

ISO 3664:2009 specifies the standard viewing condition to perform visual assessment of images. The light source of the viewing booth should be allowed to stabilize in color temperature for at least 30 min and must match D50 (chromaticity coordinates x_{10}= 0.3478 and y_{10}=0.3595) at the end of this period; it must have a metamerism index of less than 1.5 (less than 1 is recommended).

All other light sources shall be reduced or turn off. All extraneous materials shall be removed from the sides and back of the booth.

In the ISO 3664:2009 P1 viewing condition, illuminance must be 2000 lx ± 500 lx. “For a viewing area up to 1 meter square, the illuminance at any point within the illuminated area shall not be less than 75% of the illuminance measured at the center of the illuminated viewing surface area. For larger areas, the lower limit shall be 60%” (ISO 3664, 2008, p. 8).

The surround and backing must be neutral and matt (luminous reflectance between 10% and 60%). The ratio of the surround luminance must be 1.0(±0.2):1. The surround must extend beyond the subjects being viewed on all sides by at least 1/3 of their dimensions (ISO 3664, 2008).

The standard image being viewed and observer’s eyes must be “positioned to minimize the amount of light specularly reflected toward the eyes of an observer on or near the normal to the center of the viewing surface” (ISO 3664, 2008, p. 5).

<u>Setting Viewing and Measurement Conditions</u>

In this research, color measurement procedures conformed to ISO 13655:2009 specifications. Specifically the following measurement conditions were used for assessing conformance to ISO/DIS 15339:2009, i.e., CIE two degree standard observer at D50 illumination, instrument light source at D50 illumination (5000^o K) with known amount of UV radiation (M1), and $0^o/45^o$ or

$45^o/0^o$ instrument geometry using white backing to the print during the measurement.

Viewing conditions were set to ISO 3664:2009 P1 because it correlates to the M1 measurement conditions. The standardization of the light source at D50 with specified amount of UV energy in both measurement and viewing conditions, allows printing by the numbers, using the substrate corrected dataset, which should lead to agreement between measured results and visual assessment.

Chapter 4

Research Question

Before the usage of OBAs in printing papers, M0 measurement condition correlated well to visual perception under ISO 3664:2000 viewing conditions because there were no agents that interacted with UV energy to produce visible light in the papers. As stated in the previous chapter, the viewing and measurement standards were revised at the same time. Nevertheless industry implementation was not simultaneous. Previous lamps conforming to ISO 3664:2000, allowed high tolerances in the UV region, “easy accomplished with little or no UV energy”. New lamps conforming to ISO 3664:2009 arrived in 2010 simulating Illuminant D50 more precisely (GTI, 2011). Measurements continued to be made under M0 conditions and did not correlate to the revised ISO 3664 D50 viewing condition, and this created a significant problem.

Numbers are relevant if they correlate to visual perception. To follow the *metamerism* concept, a conditional match depends on the lighting, object, and observer. The lighting condition appears in the measurement instrument and the viewing booth. Thus, if one changes, for instance the lamps installed in the viewing booth, the light source of the measurement instrument must change as well in order to preserve a good correlation between visual perception and color measurement. When ISO 3664:2009 D50 bulbs were available in the market, but only M0 instruments were available, the match between prints on highly OBA loaded prints and non-OBA proofs was compromised. The solution was to introduce spectrophotometers conforming to ISO 13655:2009, however, the first M1 instrument was only announced in 2011 (Konica Minolta, 2011), and the biggest instrument manufacturer did not unveil its instrument until April 2012 (X-Rite, 2012). RIT requested and was among the first universities to receive these new instruments for testing.

With consistent lighting available in its light booths and instruments, a new approach to restoring visual print-to-proof match suggested itself. ISO/DIS 15339-1 introduced the concept of Substrate Corrected Colorimetric Aims (SCCA), and it appeared that proofing to print-side Substrate Corrected Colorimetric Aims held great promise for restoring visual print-to-proof match in an environment conforming to ISO 3664:2009 and ISO 13655:2009. Since, no research could be found where the SCCA technique was implemented as the proofing aims using M1 measurement conditions and assessing quality of print-to-proof visual match according ISO 3664:2009 P1 viewing condition, this was also an opportunity for the researcher to conduct original research. Thus, this research focuses on the implementation of the SCCA technique in a color-managed workflow to prepare a proof. The objective of this SCCA-proof is to match a print on highly OBA loaded paper. The research takes advantage of the updated viewing and measurement conditions in ISO 3664:2009 and ISO

13655:2009 in its implementation. Testing the SCCA technique leads directly to the primary research question:

1. Will a color-managed proof that conforms to a print-based substrate corrected dataset on non-OBA paper visually match a print on OBA paper?

In order to verify the meaningfulness of the SCCA technique, the match using non-OBA production stock, and the resulting mismatch when printing on OBA loaded paper but proofing to current standard, ISO 12647-7, needed to be reproduced. This led to two further research questions:

2. Will an ISO 12647-7 compliant proof on non-OBA paper match an ISO 12647-2 compliant print on non-OBA paper?
3. Will an ISO 12647-7 compliant proof on non-OBA paper demonstrate a mismatch to an ISO/DIS 15339 compliant print on OBA paper?

Finally, color measurement and software suppliers have independently introduced solutions to the problem reported by the printing industry. A third party solution was chosen for this research. This led to the fourth research question:

4. Will a proof on non-OBA paper prepared using a third party solution match an ISO/DIS 15339 compliant print on OBA paper?

Limitations

1. The color measurement condition must conform to ISO 13655 (2009) M1.
2. Visual examination of the proof and print must be carried out in an ISO 3664:2009 P1 condition compliant viewing booth. Viewing either the print or the proof alone is outside the scope of this research.
3. Stability of the paper with OBA must have a negligible effect during the period of the experiment.
4. Digital tools and software must allow the production of color managed images and test targets.

Chapter 5

Methodology

Overview

The methodology used to answer the research questions consisted of two phases: Phase I - preparing print and proof samples to assess visual match and Phase II - conducting a psychometric experiment under controlled viewing conditions to assess the degree of visual match between prints and proofs. Each phase is discussed separately below.

Phase I. Preparing Samples for Print to Proof Visual Match

Process Flow

A five-step process was used to prepare samples for print-to-proof visual match. A flowchart describing these steps is shown below (Figure 1). The sections following this flowchart describe this step-by-step process in greater detail.

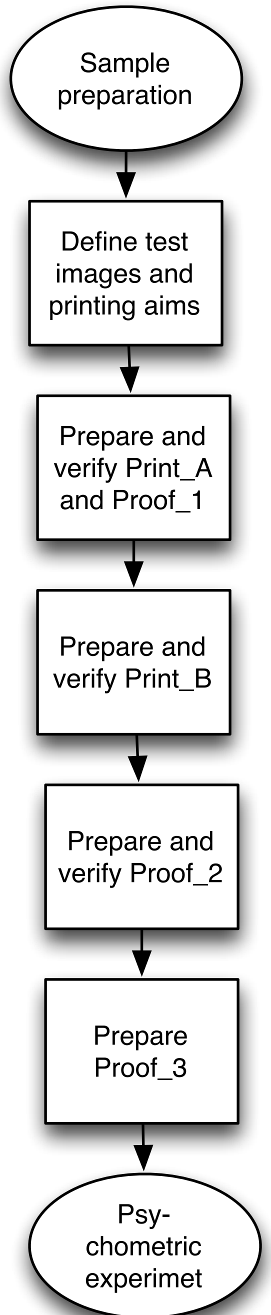

Figure 1. Flowchart for sample preparation for print-to-proof visual match

Select Test Images.

The IT8.7/4 target (1,617 color patches) was used to assess characterization data set conformance. In addition, two test images were used to assess the effectiveness of print-to-proof match using the approaches described above.

1. High-key neutral image: a High-key neutral image was chosen because the effect of OBAs is greater when the ink coverage is low and the colors being rendered are near neutrals.
2. Three Musicians (multi-hue image): this image was chosen because it is more typical of the colorful images printed commercially.

Appendix A shows the images used to prepare the test form.

Sample Preparation

Offset Press Simulation

The Kodak Approval imaging system was used to simulate an offset press because:

- The Kodak Approval is more repeatable than an offset lithographic press.
- The Kodak Approval can simulate offset lithographic dot gain and solid coloration independently.
- Preparing prints using the Kodak Approval is faster and less expensive than preparing similar prints on an offset press.

Prepare Print A

Print A was prepared using the Kodak Approval to simulate an offset press printing in conformance to ISO 12647-2. Solid, midtone and three quarter tone patches from the IT8.7/4 were measured (M0 condition) and conformance was assessed using ISO 12647-2 aims and tolerances. Appendix F shows how conformance to ISO 12647-2 was demonstrated.

Prepare Print B

Print B was prepared using the Kodak Approval to simulate an offset press print using the Fogra39_SCCA characterization dataset on OBA loaded paper. The IT8.7/4 target was measured (M1 condition) and conformance to these aims was assessed using CGATS TR016 tolerances. Appendix H shows how conformance to CGATS TR016 was demonstrated.

Proofing System

A description of the proofing system and calibration process used in this research is documented in Appendix C.

Prepare Proof 1

Proof 1 was prepared using the published Fogra39 characterization dataset on conforming semi-matte proofing paper. An IT8.7/4 target was measured (M0 condition) and conformance was assessed using ISO 12647-7 aims and tolerances. Appendix H shows how conformance to ISO 12647-7 was demonstrated.

Prepare Proof 2

Proof 2 was prepared using the proofing system described in Appendix D. The print-based Fogra39_SCCA characterization dataset was used as the proof aim, and the proof was printed on a standard semi-matte proofing paper. The IT8.7/4 target was measured (M1 condition) and conformance was assessed using ISO/DIS 15339-1 aims and tolerances. Appendix I shows conformance to CGATS TR016 was demonstrated.

Prepare Proof 3

Proof 3 was prepared to match Print B on OBA loaded paper, using X-Rite's Optical Brightening Agent Compensation (OBC) Module. The OBC Module was used to build a custom ICC profile according to Appendix E. The advantage of this solution is that an M1 instrument is not required for profiling. Instead, the method uses a M0 instrument (i.e. X-Rite i1 iSis XL) and introduces additional data collected by visually matching a grey scale printed on OBA loaded production paper with the X-Rite OBC reference grey scale viewed under D50 light conforming to the ISO 3664:2009 specification.

A summary of the printing and proofing conditions are shown in Table 1 and Table 2 respectively.

Table 1. Printing Specifications

Printing Condition	Substrate	Substrate CIELAB (M1)	Aims	Substrate corrected	Tolerances	Measurement Condition
A	ISO 12647-2 PT1	(93, 1, -4)	Fogra39	No	ISO 12647-2	ISO 13655 M0
B	Premium coated with OBA	(94, 3, -9)	Fogra39 SCCA	Yes	ISO/DIS 15339-1	ISO 13655 M1

Table 2. Proofing Conditions

Proofing Condition	Substrate	Substrate CIELAB (M1)	Proofing Aims	Prepare to match	Measurement Condition
1	GMG S.M. 250	(96, -1, -1)	Fogra39	Print A	ISO 13655 M0
2	GMG S.M. 250	(96, -1, -1)	Fogra39 SCCA	Print B	ISO 13655 M1
3	GMG S.M. 250	Aligned to the viewing condition (96, -1, -1)	Fogra39 customized using OBC	Print B	ISO 13655 M0

The main printing variable was the OBA content of the paper. One printing paper conforms to ISO Paper Type 1 (PT1) and ISO 12647-2 aims/tolerances were used with this paper. The second paper does not conform to PT1 due to the presence of high levels of OBA. In this case, the Fogra39 published dataset was adjusted to the production paper's white point measured under the M1 measurement condition and a custom ICC profile was built based on the Substrate-Corrected Colorimetric Aims (SCCA).

The proofing side depends on how the print was prepared. If PT1 was used (i.e. Print A), the proof was made to match the published Fogra39 dataset and tolerances were taken from ISO 12647-7. This sample became Proof 1. If OBA loaded paper was used (i.e. Print B), the proof was made in two ways. First, a proof was prepared to match the print based Fogra39_SCCA dataset (Proof 2). Second, a proof was prepared using X-Rite's OBC Module (Proof 3).

With the print and proofs defined, produced, and verified, the next steps were to define the simulation environment for preparing the prints, define the environment for preparing the proofs, and define the measurement environment for assessing visual print-to-proof conformance.

Phase II. Psychometric Experiment

Process Flow

A four-step process was used to perform a psychometric experiment under controlled conditions, namely a paired comparison experiment under ISO 3664:2009 D50 lighting. A flowchart describing these steps is shown below in Figure 2. The sections following this flowchart describe the step-by-step process in greater detail.

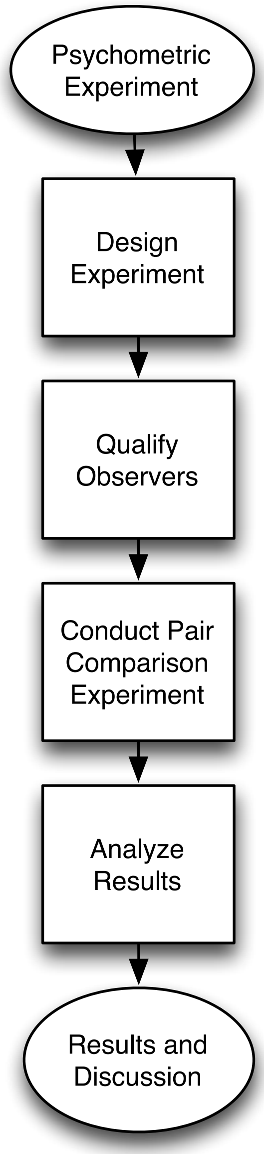

Figure 2 - Flowchart psychometric experiment

Experimental Design

To conduct a psychometric experiment, the prepared prints and proofs were combined into pairs for visual assessment. Four pairs were assessed. Pair 1 was the base or anchor case. Paper Type1 was used for the print, and the print and proof conform to ISO 12647-2 and ISO 12647-7 respectively. A high-quality visual print-to-proof match was anticipated. Pair 2 was the problem case, printing on OBA loaded paper using SCCA, but proofing to match the published Fogra39 dataset. A print-to-proof mismatch was expected. Pairs 3 and 4 are based on the printing conditions used to prepare Print B. They differ in the proofing solutions used. The Pair 3 proof was prepared to match the print-based SCCA Fogra39 dataset. The Pair 4 proof was prepared using X-Rite's OBC Software. The relationship between the pairs and the research questions is shown in Table 3.

Table 3. Research questions vs. print-proof pairs

Objective	Pair	Print	Proof	Viewing Condition
Demonstrate print-to-proof visual match when the print is on paper without OBA.	1	A	1	ISO 3664 P1
Demonstrate print-to-proof visual mismatch when the print is on OBA loaded paper.	2	B	1	ISO 3664 P1
Assess the visual match between a proof using the substrate corrected dataset and a TR016 conformed print on OBA loaded paper.	3	B	2	ISO 3664 P1
Assess the visual match between a proof prepared using OBC software and a print on OBA loaded paper.	4	B	3	ISO 3664 P1

Qualify Observers

Observers were invited to join the experiment using the informed consent procedure published by RIT’s Institute Review Board. Consenting volunteers took the Farnsworth-Munsell 100 Hue Test to assess the quality of each observer’s color vision. The best observers were chosen for the paired comparison test.

Conduct a Psychophysical Experiment to Assess of Proof-to-Print Match

A paired comparison psychophysical experiment was performed using the four print-to-proof pairs described in Table 3. The paired comparison was a simple binary choice. A set of stimuli consisting of two print-to-proof pairs was presented to the observer. The observer chose the pair with the better quality of match between print and proof. All possible sets were presented to each observer. A paired comparison experiment was chosen because it is simple and uses comparative judgments. The paired comparison method does not require an absolute measure of print-proof match. Instead, the observer determines, when two pairs of print-proofs are presented, which pair has the better visual match than the other pair. The method of paired comparisons takes advantage of human familiarity with and ability to make comparisons.

Figure 3 shows the layout of a set of stimuli used in the experiment.

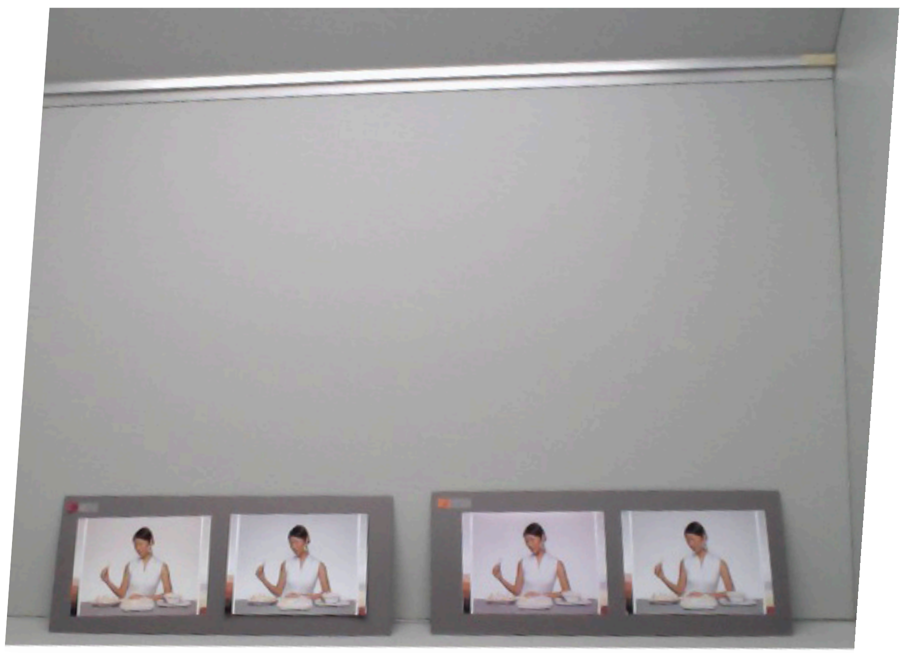

Figure 3. Paired comparison layout

There are four print-to-proof pairs. In order to conduct a paired comparison, it was necessary to compare each print-proof pair with the other three pairs under the ISO 3664:2009 P1 compliant viewing booth. This led to six paired evaluations as shown in Table 4.

Table 4. Paired comparison evaluations

	Pair		Pair	
Paired comparison 1	Pair 1		Pair 2	
	Print A	Proof 1	Print B	Proof 1
Paired comparison 2	Pair 1		Pair 3	
	Print A	Proof 1	Print B	Proof 2
Paired comparison 3	Pair 1		Pair 4	
	Print A	Proof 1	Print B	Proof 3
Paired comparison 4	Pair 2		Pair 3	
	Print B	Proof 1	Print B	Proof 2
Paired comparison 5	Pair 2		Pair 4	
	Print B	Proof 1	Print B	Proof 3
Paired comparison 6	Pair 3		Pair 4	
	Print B	Proof 2	Print B	Proof 3

During the experiment, the images did not have any visible identifying marks; only the person running the experiment knew which was the proof and which was the print.

A visual examination of print-to-proof pairs was conducted one observer at a time. Before the experiment, each observer was required to complete training to understand the criteria being studied: quality of visual match. The time required for training also allows the observer to adapt his/her eyes to the lighting conditions. During the evaluation the observer viewed the proof-print pair from multiple locations around the viewing booth. Observations were recorded.

Results were collected as the observer made judgments during the experiment. For each observer, the experiment was repeated two times, once with the High-key image and once with the Three Musicians image (see Appendix A).

Analyze Results

From the resulting observations, each judge was first tested for internal consistency (i.e. if the judge ranked A>B and B>C, then the judge must rank A>C to be consistent). This was accomplished by examining each observer's responses for triads. A triad is a circular behavior (e.g. A > B and B > C, but C > A), meaning that the observer could not distinguish among the pairs, or was guessing incorrectly. If a triad was found, the observer's responses were removed from the experiment. Second, the panel of judges was tested to determine if there was agreement among judges or not (at a 95% level of confidence). Disagreeing judges will produce random results that will align with one another only by chance. Thus, a nonparametric statistic can be developed to assess the probability of chance alignment of rankings.

Data from consistent and agreeing observers led to a ranking of print-to-proof pairs from best perceived match, to second best, third best, and worst perceived match. Finally, experimental results were tested to determine if a statistically significant difference among print-to-proof pairs existed.

Rickmers (2000) developed tables for critical values for agreement among judges and real differences among prints based on non-parametric statistics. The critical values are at 95% level of confidence. Tables are shown in table 5 and 6 respectively.

Table 5 – Critical values for significance of agreement among judges

		Number of Consistent Judges		
Number of prints		**5**	**6**	**7**
	3	64.4	103.9	157.3
	4	88.4	143.3	217.0
	5	112.3	182.4	276.2
	6	136.1	221.4	335.2

Table 6 – Critical values for test for real difference among prints

		Number of Consistent Judges		
Number of prints		**5**	**6**	**7**
	3	6-14	8-16	10-18
	4	7-18	9-21	11-24
	5	8-22	10-26	12-30
	6	9-26	11-31	14-35

Chapter 6

Results

Overview

Seven observers with good to excellent color vision (as demonstrated by the Farnsworth-Munsell 100 Hue Test) were invited to participate in the paired comparison experiment. The criterion to invite them was to have zero three-cap transposition. The experiment was conducted in accordance with the methodology described in Chapter 5 and the results are summarized below.

Because paired comparison experiments use non-parametric statistics a relatively small number of observations are required to obtain statistically significant results. The four-step process described in the methodology was used to remove noise from and analyze the experimental data.

Results

High-key Image

1. Judge's Consistency

   Judge's observations are shown in Table 7. The quality of visual match perceived as the best received a score of 4, the second best 3, the third best 2, and the worst a score of 1.

Table 7 – Judge's consistency, High-key image

Pair	Judge 1	2	3	4	5	6	7		Ave
1: Anchor Pair	3	2	2	2	2	2	2		2.1
2: Problem Pair	1	1	1	1	1	1	1		1.0
3: SCCA Pair	4	4	4	4	4	4	4		4.0
3: OBC Pair	2	3	3	3	3	3	3		2.9
Triads Found	0	0	0	0	0	0	0		

For instance, judge 1 perceived the SCCA pair as the best match (score of 4), the Anchor Pair as second (score of 3), the OBC Pair as third, and the Problem Pair as the worst match (score of 1). No triads were found; hence, all judges are consistent.

2. Agreement among Judges

   A statistical test for agreement among judges was conducted at 95% level of significance. Table 8 shows the judges' responses and the test statistic, the sum of squares of differences between observed results and the expected value (17.5) if there was no agreement among judges. For there to be significant agreement among judges, the test statistic must exceed the critical value shown in Table 5. In this case, the sum of squares has to be greater than 217. Since it is 233, there is agreement among judges. The coefficient of concordance W is 0.95, this means that the observers agree pairwise approximately 95% of the time.

Table 8 – Agreement among judges

Pair	Judge 1	Judge 2	Judge 3	Judge 4	Judge 5	Judge 6	Judge 7	1: Sum	2: Ave Total	3: Total - Aver.	4: (Total - Ave)^2
1: Anchor Pair	3	2	2	2	2	2	2	15	17.5	-2.5	6.25
2: Problem P.	1	1	1	1	1	1	1	7		-10.5	110.25
3: SCCA Pair	4	4	4	4	4	4	4	28		10.5	110.25
3: OBC Pair	2	3	3	3	3	3	3	20		2.5	6.25
Sum								70			233.00

3. Rank

The average score for each pair shown in Table 7 leads to a ranking among the pairs. For the High-key image, the best pair was the SCCA, the second best was the OBC Pair, the Anchor pair ranked third, and the Problem Pair was judged to have the worst match. Table 9 shows the ranking for each pair together with its printing and proofing condition.

Table 9 – High-key image ranking

Quality of Match	Pair	Printing Condition	Proofing Condition
Best	SCCA Pair	Print B	Proof 2
Second	OBC Pair	Print B	Proof 3
Third	Anchor Pair	Print A	Proof 1
Worst	Problem Pair	Print B	Proof 1

4. Real Differences among Prints

For a pair to be statistically significant different from the other pairs (at a 95% confidence level, according Table 6), the sum of ranks for all judges must be for a given pair must be lower than 11 or greater than 24. This sum is shown in the "Sum" column of Figure 8. When the print-to-proof quality of match of the High-key image was assessed, two pairs were identified to be statistically different from the others: the SCCA Pair and the Problem Pair. The SCCA Pair scored 28, the maximum possible score which is greater than the upper critical value of 24. The Problem Pair scored 7, the minimum possible score, which is less than the lower critical value. The pair that ranked second was the OBC Pair, scoring 20. The Anchor Pair, which ranked third, has a score of 15. Neither of these pairs were above or below the critical values and neither was shown to be significantly different from the others.

<u>Three Musicians Image</u>

1. Judge's Consistency and Ranking

When assessing the Three Musicians Image, all judges provided consistent answers, no triads were found. See Table 10.

Table 10 - Judge's consistency, Three Musicians Image

Pair	Judge 1	2	3	4	5	6	7	Ave
1: Anchor P.	3	4	3	3	2	2	1	2.6
2: Problem P.	1	2	1	1	1	1	2	1.3
3: SCCA Pair	4	3	4	4	4	4	3	3.7
3: OBC Pair	2	1	2	2	3	3	4	2.4
Triads Found	0	0	0	0	0	0	0	

2. Agreement among Judges

Once again agreement among judges is tested by comparing the test statistic to the critical value of 217. For the Three Musicians Image, the sum of column 4 equals 145; therefore, there is no significant agreement among judges. Although the noise induced by disagreement could obscure the signal in the experiment, in this case a clear signal emerged despite the lack of agreement among judges, so no judges were removed.

Table 11 - Agreement among Judges

Pair	Judge 1	2	3	4	5	6	7	1: Sum	2: Ave Total	3: Total - Aver.	4: (Total - Ave)^2
1: Anchor Pair	3	4	3	3	2	2	1	18	17.5	0.5	0.25
2: Problem P.	1	2	1	1	1	1	2	9		-8.5	72.25
3: SCCA Pair	4	3	4	4	4	4	3	26		8.5	72.25
3: OBC Pair	2	1	2	2	3	3	4	17		-0.5	0.25
Sum								70			145

3. Rank

The average score for each pair leads to a rank. For the Three Musicians, the best pair was the SCCA pair, the Anchor Pair ranked second, the OBC pair ranked third, and the Problem Pair was the worst match. Table 12 shows the ranking for each pair and its associated printing and proofing condition.

Table 12 – Three Musicians image ranking

Quality of Match	Pair	Printing Condition	Proofing Condition
Best	SCCA Pair	Print B	Proof 2
Second	Anchor Pair	Print A	Proof 1
Third	OBC Pair	Print B	Proof 3
Worst	Problem Pair	Print B	Proof 1

4. Real Differences among Prints

For a pair to be statistically significant different from the other pairs, the sum of all judges' rankings must be lower than 11 or greater than 24. When the print-to-proof quality of match of the Three Musicians image was assessed, two pairs were identified to be statistically different from the others: the SCCA Pair and the Problem Pair. The SCCA Pair scored 26 (>24), and the Problem Pair scored 9 (<11). The pair that ranked second was the Anchor Pair, scoring 20. The OBC Pair, which ranked third, has a score of 15. Neither pair is significantly different from the others.

Summary

For the High-key and Three Musicians images, the pair with the best quality of match was the SCCA pair (Print B and Proof 2) and the one with the worst quality of match was the Problem pair (Print B and Proof 1). Both pairs, SCCA and Problem, were found to be statistically different from the rest. Tables 13 and 14 summarize the results for the High-key and Three Musicians images respectively.

Table 13 – High-key image summary

Quality of Match	Condition	Statistically Significance
Fist	SCCA Pair	Yes
Second	OBC Pair	No
Third	Anchor Pair	No
Worst	Problem Pair	Yes

Table 14 – Three Musicians image summary

Quality of Match	Condition	Statistically Significance
Fist	SCCA Pair	Yes
Second	Anchor Pair	No
Third	OBC Pair	No
Worst	Problem Pair	Yes

Discussion

As a follow-up to the paired comparison test, two points of worthy further exploration are analyzed: (1) why the anchor pair was not chosen as the best match, and (2) a colorimetric comparison of image contents between print and proof for the two statistically pairs with significant differences.

Anchor Pair Analysis

The Anchor Pair (print conforming to ISO 12747-2 and proof conforming to ISO 12647-7) defines an acceptable print-to-proof match. If there are no OBAs in production paper, an ISO 12647-7 conforming proof should match an ISO 12647-2 conforming print. The Anchor Pair did not produce the best quality of print-to-proof match. Instead, it was ranked in third place for High-key image and in second place for the Three Musicians. The most probable explanation for this unexpected result is that there are OBAs in the substrate used for Print A (i.e. Sappi Flo). Table 15 shows the CIELAB values for each substrate used under ISO 13655:2009 M0 and M1 condition. The use of OBAs in offset lithography printing papers has become pervasive in the industry because OBAs represent a cheaper alternative to achieve high levels of brightness using less expensive pulps.

Sappi Flo was specifically chosen because it was the closest available grade to Paper Type 1. Yet, this paper which when measured under M0 condition is highly conforming to ISO 12647-2 Paper Type 1 (PT1), when measured under M1 condition yielded a CIE b* nearly minus four. The high level of b* compromised the anchor pair match because ISO 3664:2009 D50 is highly sensitive to OBAs.

Table 15 – Substrate specifications

Substrate	Condition	L	a*	b*	ISO brightness
Sappi Flo Print A	M0	92.7	1.4	-2.6	83.9
	M1	92.9	1.4	-3.7	
Sappi McCoy Print B	M0	93.5	2.6	-7.0	91.8
	M1	93.8	2.6	-9.1	
GMG SM 250 Proofing	M0	95.6	-0.9	-0.9	90.2
	M1	95.6	-0.9	-0.9	
Published dataset Fogra39		95.0	0.0	-2.0	

It is no longer reasonable to assume that today's PT1 substrates will yield the visual results, in terms of print-to-proof match, that they did when the ISO 12647-2 was first published. As said before, when using PT1 substrates containing OBAs and proofing to ISO 12647-7, the visual print-to-proof match is compromised.

Colorimetric Comparison of Image Content

Figure 4 compares the SCCA pair to the Problem pair in terms of quality of color match. Because the match is metameric, all comparisons were made using D50, M1, 2° measurement conditions, which correspond to the viewing conditions used in the paired comparison experiment (ISO 3664:2009).

Five colors of interest plus the substrate's white point were selected from the High-key image and the color differences for the two print-to-proof pairs are shown. For each pair the color differences between the print and the problem proof (Proof 1) is shown by a red line in an a*, b* plot. The color differences between the print and the SCCA proof (Proof 2) is show by the green line in the a*/b* plot. The two lines meet at the target actual color of the print on heavily OBA loaded paper.

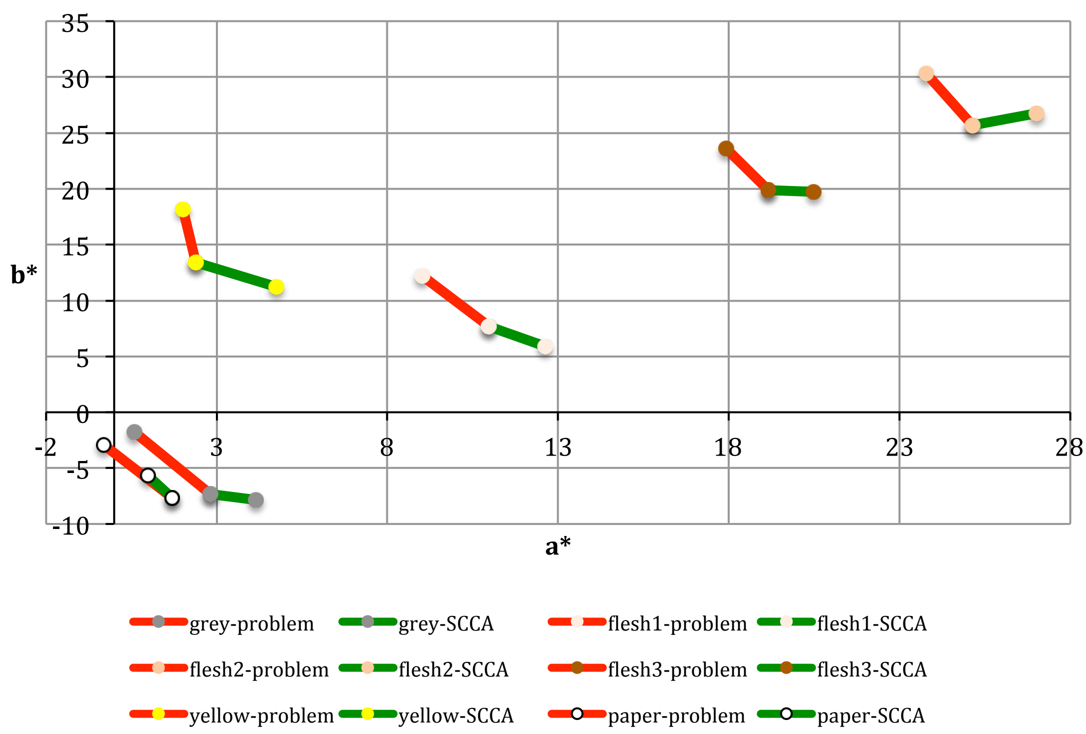

Figure 4 – a*/b* plot of colors of interest from the High-key image

As the figure clearly demonstrates, the SCCA proof to print pair has less than half of the color differences of the Problem proof to print pair. For the maximum difference (a medium grey) the SCCA proof to print pair is 4x better. This explains the clear preference shown by observers for the SCCA proof to print pair in the paired comparison experiment.

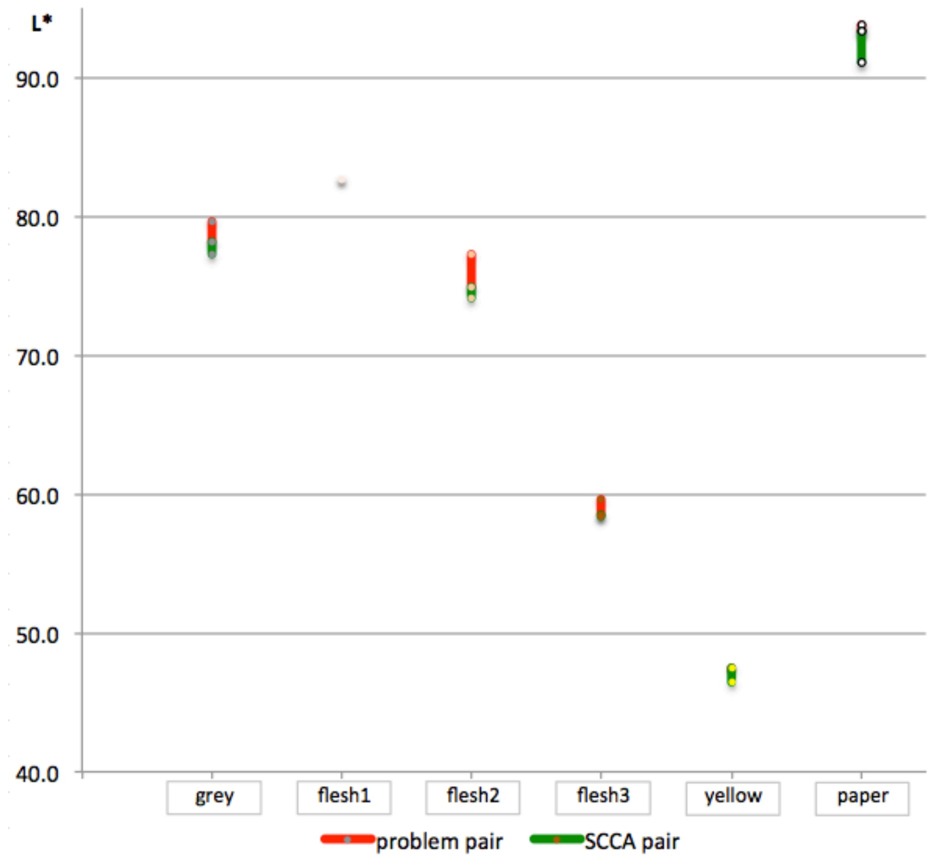

Figure 5 – Problem and SCCA pair L* differences

The L* error comparison between the Problem and SCCA pairs is shown in Figure 5 for the same 5 colors of interest from the High-key image, plus the substrate's white point. As the figure shows, (1) the paper white point of the SCCA pair has a greater L* error than the paper white of the Problem pair, and

(2) the Problem pair has less difference in the yellow and lighter flesh tone than the SCCA pair.

The experimental SCCA technique cannot correct out-of-gamut colors, including colors that are lighter than the substrate. This is because L* decreases as ink is deposited on paper. SCCA does correct the overall bluish cast introduced by optical brighteners by color managing the image, meaning that the technique adds colorant to the paper. Because using the print-based substrate corrected dataset as the proofing aims adds colorant and decreases L*, the level of L* error will be the minimum if the proofing substrate has a greater L* value than production paper.

The SCCA technique works better in the darker flesh tones and medium grey. These three colors are predominant in the High-key image, explaining why the SCCA pair was chosen as the best quality of print-to-proof visual match.

Ultimately, the quality of print to proof match reflects the quality of color management in the agreed viewing environment. This research shows that M1 measurements are highly predictive of visual judgments in an ISO 3664:2009 viewing environment. This finding should encourage the widespread use of these new measurement and viewing conditions to more accurately reflect the impact of today's heavily optically brightened papers on perceived color. In addition, the research shows that one approach to color management, the use of print-based SCCA, is an improving direction that points the way for further work and potentially even greater reduction of color error.

Chapter 7

Summary and Conclusion

Summary

To answer the research question, "Will a color-managed proof that conforms to the print-based substrate-corrected dataset on non-OBA paper visually match the print," psychometric experiments were carried out using two pictorial color images, with proofs and prints prepared according to the methodology. The results showed that the problem pair, an OBA print and ISO 12647-7 proof, was ranked the as the worst match. This confirms the problem faced in the graphic arts industry. The results also showed that the SCCA pair, an OBA print and SCCA proof, was ranked as the best match. This finding suggests that the proposed SCCA technique is a viable solution to improve visual match between OBA print and non-OBA proof. In addition, colorimetric analysis of image contents suggested that there is room for print-to-proof improvement when printing and proofing to the substrate-corrected characterization dataset with the use of color management.

The match of non-OBA proofs with OBA prints is metameric. Therefore, it depends on the lighting, object, and observer. The alignment introduced by ISO 3664:2009 and ISO 13655:2009 for viewing and measurement conditions takes into account the impact of OBAs on the paper and printed colors. Color management has been demonstrated to be the tool that reduces color differences and improves print-to-proof visual match when papers with optical brightening agents are measured and viewed in conditions conforming to these revised standards.

Implications, Limitations, and Future Research

The primarily limitation of the research conducted in this thesis is that the print was simulated using a Kodak Approval rather than printed on a conventional offset press. In order to improve the applicability of this research to real world printing conditions, it would be useful to repeat the research using a production offset press to produce the prints. Shortly after completing his thesis work, the researcher had the opportunity to extent this methodology to match prints produced on RIT's web offset press. The results were once again highly encouraging and should motivate the industry to introduce proofing to press side SCCA corrected datasets as a commercial practice.

Two obstacles remain to be overcome before the industry can adopt press side SCCA corrected datasets in production proofing. First, the only M1 spectrophotometers currently available are handheld devices. Using such devices to measure an IT8.7/4 target is a tedious and time consuming process which required four to six hours of the researcher's time every time that a target had to be measured. Second, although proofing to a press side SCCA corrected datasets was shown to be a significant improvement over today's proofing practices, colorimetric analysis of image contents suggested that there is still room for improvement. The natural direction for improving print-to-proof match is to modify the color management workflow used to produce the proofs and this would be a fruitful for future research.

Finally, RIT is ideally positioned to collaborate with spectrophotometer and color management software suppliers to overcome the obstacles discussed above. This is an opportunity well worth capturing.

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Appendix A

Test Form

Figure A1. Test Form – Page 1

Figure A2. Test Form – Page 2

Appendix B

Offset Lithography Simulation: Kodak Approval

1. Calibration process

The Kodak Approval needs calibration to work properly. This is achieved in two steps: laser power calibration and Solid Area Density (SAD) calibration.

a. Perform Laser power calibration.

The laser calibration records the laser power output for each of the 30 lasers. See figure B1 and B2.

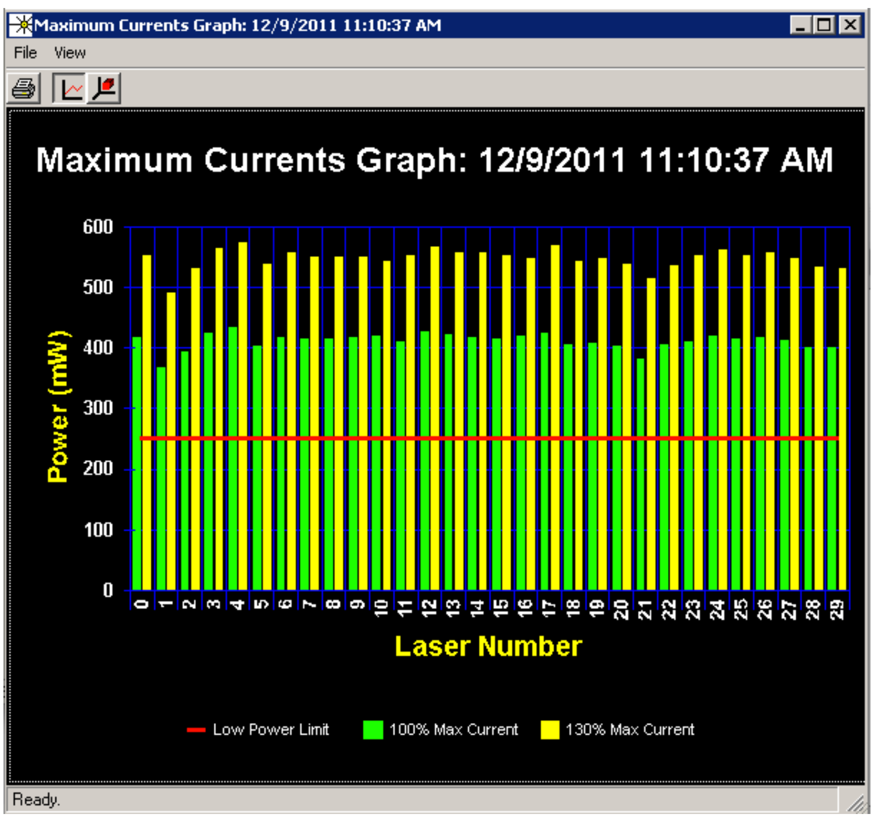


Figure B1 – Maximum currents

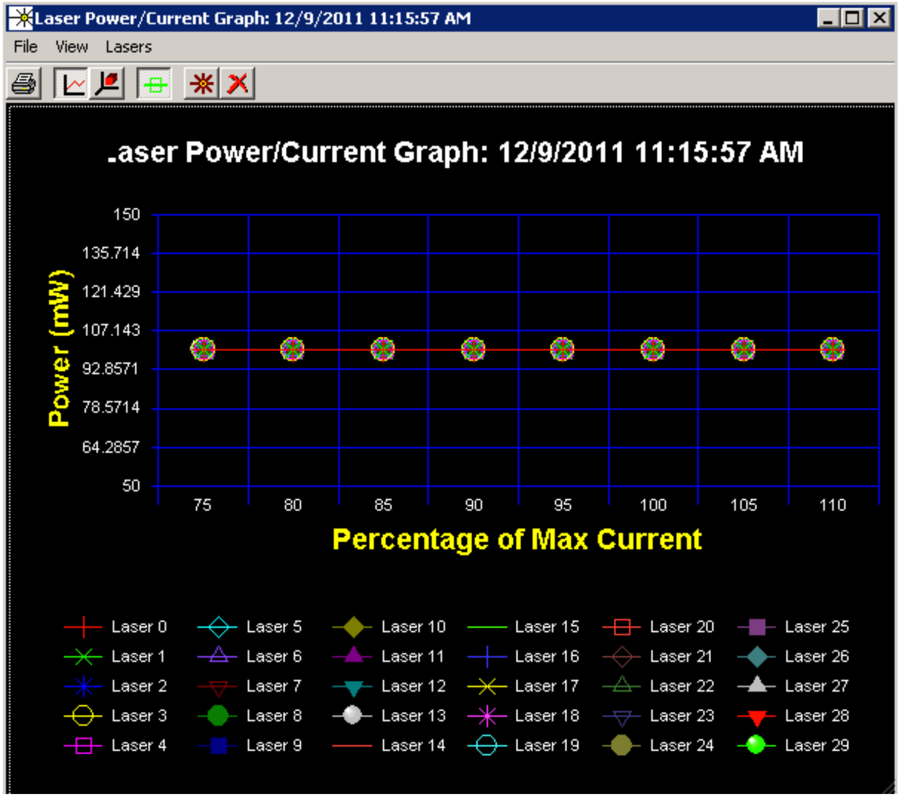
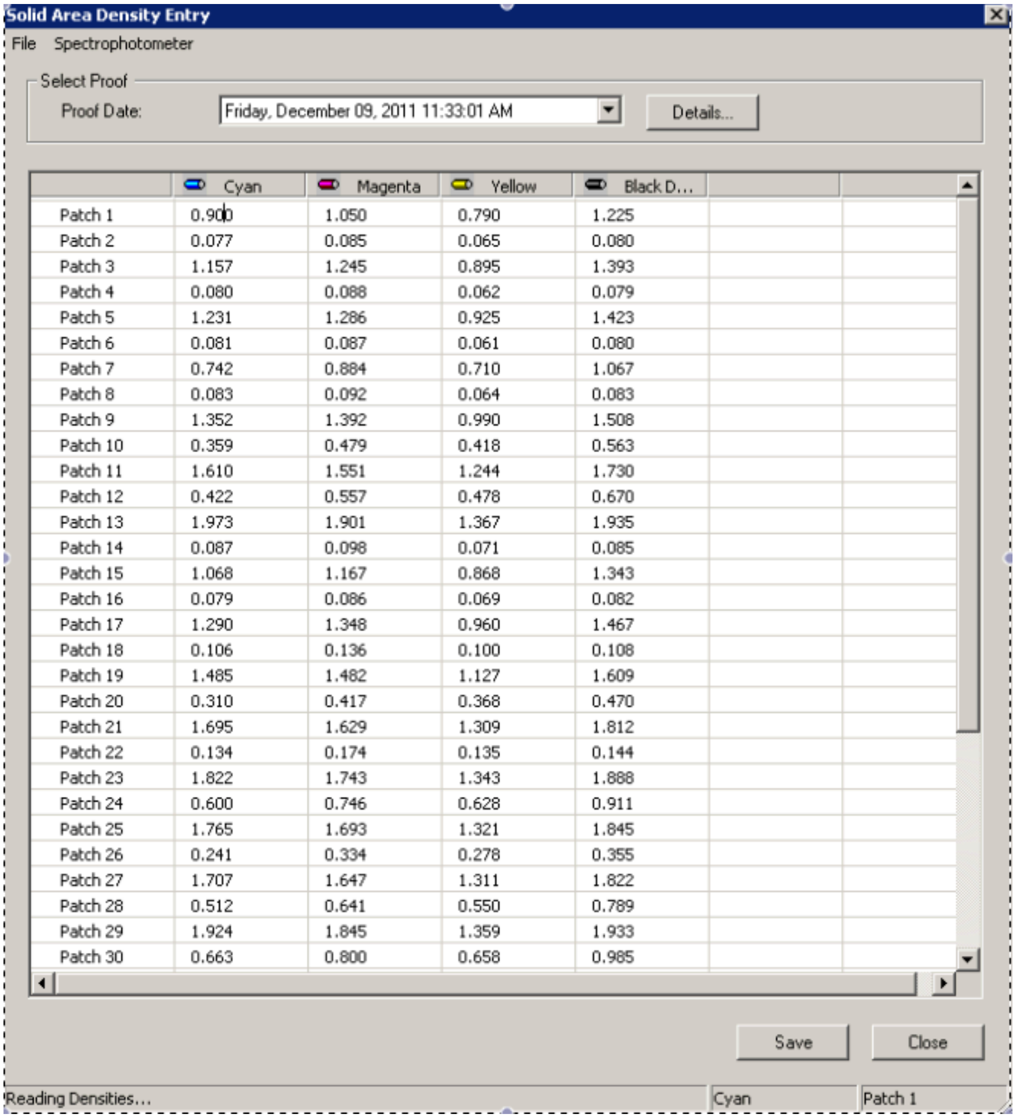


Figure B2 – Laser power/current

b. Perform Solid Area Density (SAD) calibration

The SAD calibration improves the response of the laser and corrects drifts in density values. See figure B3.



	Cyan	Magenta	Yellow	Black D...
Patch 1	0.900	1.050	0.790	1.225
Patch 2	0.077	0.085	0.065	0.080
Patch 3	1.157	1.245	0.895	1.393
Patch 4	0.080	0.088	0.062	0.079
Patch 5	1.231	1.286	0.925	1.423
Patch 6	0.081	0.087	0.061	0.080
Patch 7	0.742	0.884	0.710	1.067
Patch 8	0.083	0.092	0.064	0.083
Patch 9	1.352	1.392	0.990	1.508
Patch 10	0.359	0.479	0.418	0.563
Patch 11	1.610	1.551	1.244	1.730
Patch 12	0.422	0.557	0.478	0.670
Patch 13	1.973	1.901	1.367	1.935
Patch 14	0.087	0.098	0.071	0.085
Patch 15	1.068	1.167	0.868	1.343
Patch 16	0.079	0.086	0.069	0.082
Patch 17	1.290	1.348	0.960	1.467
Patch 18	0.106	0.136	0.100	0.108
Patch 19	1.485	1.482	1.127	1.609
Patch 20	0.310	0.417	0.368	0.470
Patch 21	1.695	1.629	1.309	1.812
Patch 22	0.134	0.174	0.135	0.144
Patch 23	1.822	1.743	1.343	1.888
Patch 24	0.600	0.746	0.628	0.911
Patch 25	1.765	1.693	1.321	1.845
Patch 26	0.241	0.334	0.278	0.355
Patch 27	1.707	1.647	1.311	1.822
Patch 28	0.512	0.641	0.550	0.789
Patch 29	1.924	1.845	1.359	1.933
Patch 30	0.663	0.800	0.658	0.985

Figure B3 – Solid area density calibration

The system must run at the following environment conditions:

- Temperature: 68-85 F.
- Relative humidity: 30-60%.

c. Approval setup

The Page Setup named: "Carlos_setup" was configured. See figure B4.

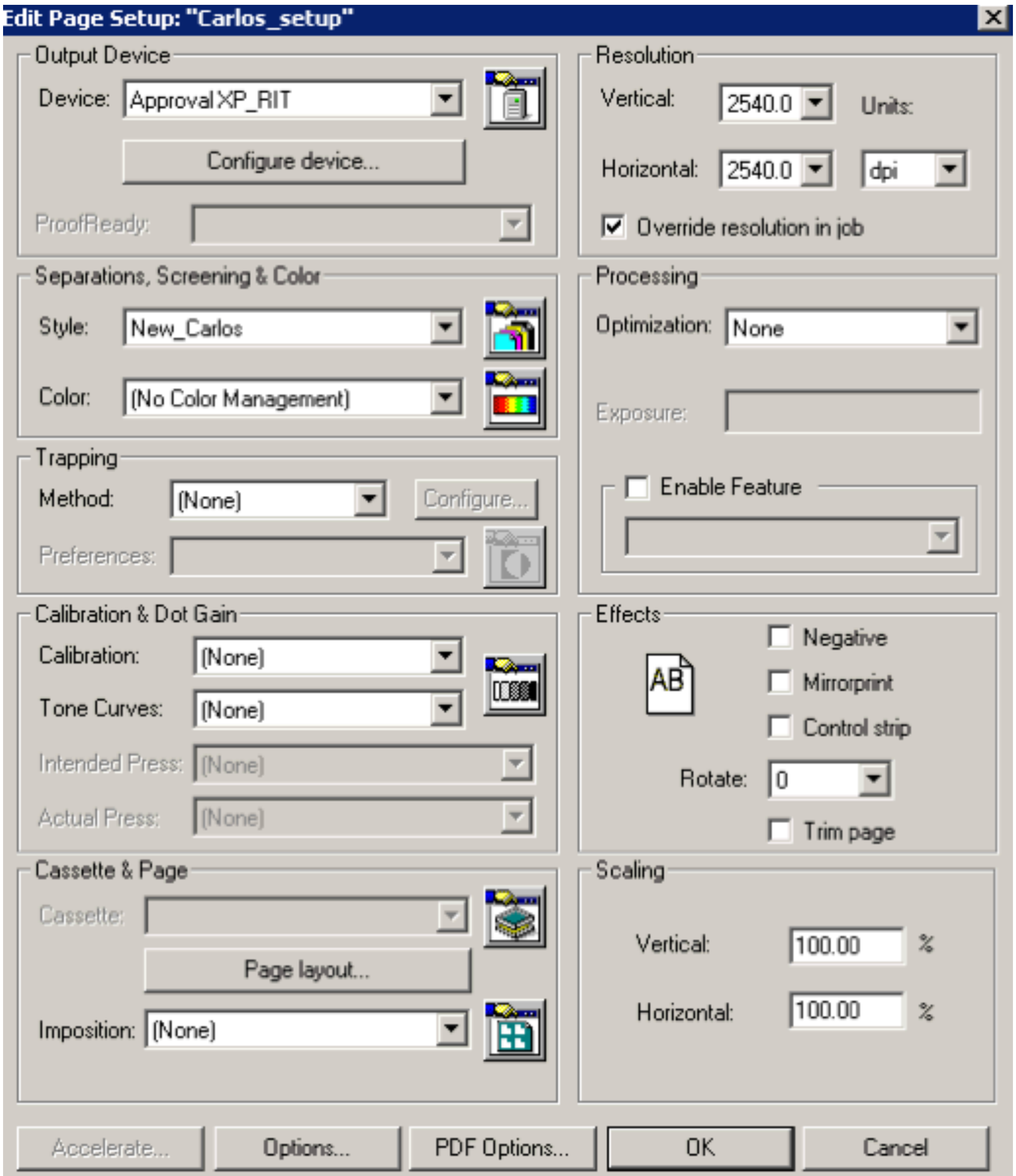


Figure B4 – Approval Setup

2. Assess conformance to ISO 12647-2 (Print A).

    i. Characterization data set: Fogra39

    ii. The ICC profile used in this workflow was built by printing an untagged (legacy) IT8.7/4 target. Readings were taken using the iSis XL at RIT Color Management Systems (CMS) Lab using X-Rite i1 Profiler.

    iii. Using the resulting Approval profile, an IT8.7/4 target was color managed to match the Fogra39 dataset.

        1. Source profile: Coated Fogra39.icc
        2. Destination profile: Approval_final.icc
        3. Rendering intent: absolute colorimetric.

b. Measure and collect data.

    i. Instrument: X-Rite i1 iSis XL
    ii. Serial number: 3695
    iii. Measurement condition: M0

c. Assess conformance to ISO 12647-2.

    i. Process solids color.
    ii. TVI

        1. At 50% tint.
        2. At 80% tint.

iii. Midtone Spread

3. Assess conformance to CGATS TR016 (Print B)

   a. Based on paper for Print B (Sappi McCoy), the published Fogra39 dataset is adjusted to the substrate following the Substrate Corrected Colorimetric Aims technique specified in ISO/DIS 15339-1.

   b. Characterization data set: Fogra39_SCCA

   c. The ICC profile used in this workflow was built by printing an untagged (legacy) IT8.7/4 target. Readings were taken using Konica Minolta FD-7 (M1 measurement condition).

      i. Using the resulting Approval profile, an IT8.7/4 target was color managed to match the Fogra39_SCCA dataset.

         1. Source profile: Fogra39_SCCA.icc

         2. Destination profile: Approval_SCCA.icc

         3. Rendering intent: absolute colorimetric.

   d. Measure and collect data

      i. Instrument: Konica Minolta FD-7 (A3E2007000)

      ii. Serial: 10001059

      iii. Measurement condition: M1

e. Assess conformance to ISO/DIS 15339-1.

   i. Compute ΔE_{00} for the dataset.

   ii. Plot CRF curves.

   iii. Assess conformance

      1. Deviation.

      2. Within sheet conformity.

Appendix C

Proofing System

1. Description of proofing system.
    a. Proofing device: HP z3200 44 inches (inkjet printing technology) running on PC/Windows.
        i. Internal X-Rite i1 spectrophotometer
    b. Proofing software: GMG Color Proof 5.0
    c. MX based color management
    d. Substrate: GMG semimatte 250 g/m^2
    e. Ink: HP Viviera ink.
        i. Cartridges: blue, green, magenta, red, yellow, gray, photo black, matte black, light cyan, light gray, light magenta, gloss enhancer.
2. GMG Color Management System

    GMG Color Proof 5.0 software uses its own Color Management System (CMS), called MX-based. GMG software simulates a target printing condition on a selected printer-substrate combination (i.e. HP z3200 and GMG proof paper semi-matte 250) by means of a *proof standard* or device link. MX color management does not covert to CIELAB as a Profile Connection Space (PCS). MX color managed workflow would be:

    1. Device-dependent input data (RGB/CMYK)

2. Proof standard (printer-substrate information)
3. Calibration set.
4. Device-dependent output (RGB/CMYK).

The Device Link profile includes all the relevant information for a specific printer-substrate combination. Each printer-substrate combination needs a proof standard (Device Link profile.) MX-based profiles (printer-substrate information) are available at GMG web page. The MX profiles are useful only if the printer-substrate combination is regularly calibrated.

3. Calibration

A regular calibration for the printer-medium (e.g. HP z3200 and GMG semimatte 250) combination guarantees production stability, repeatability and color quality.

The "calibration" mode should be selected in the control panel. The calibration is an automatically iterated process wherein the test target is printed, then measured by the internal spectrophotometer and the values are compared to GMG aims. If values are not within tolerances, Color Proof compensates by making changes to the device link and the process is repeated until good results are achieved. The proofing system calibration parameters are shown in Figure C1.

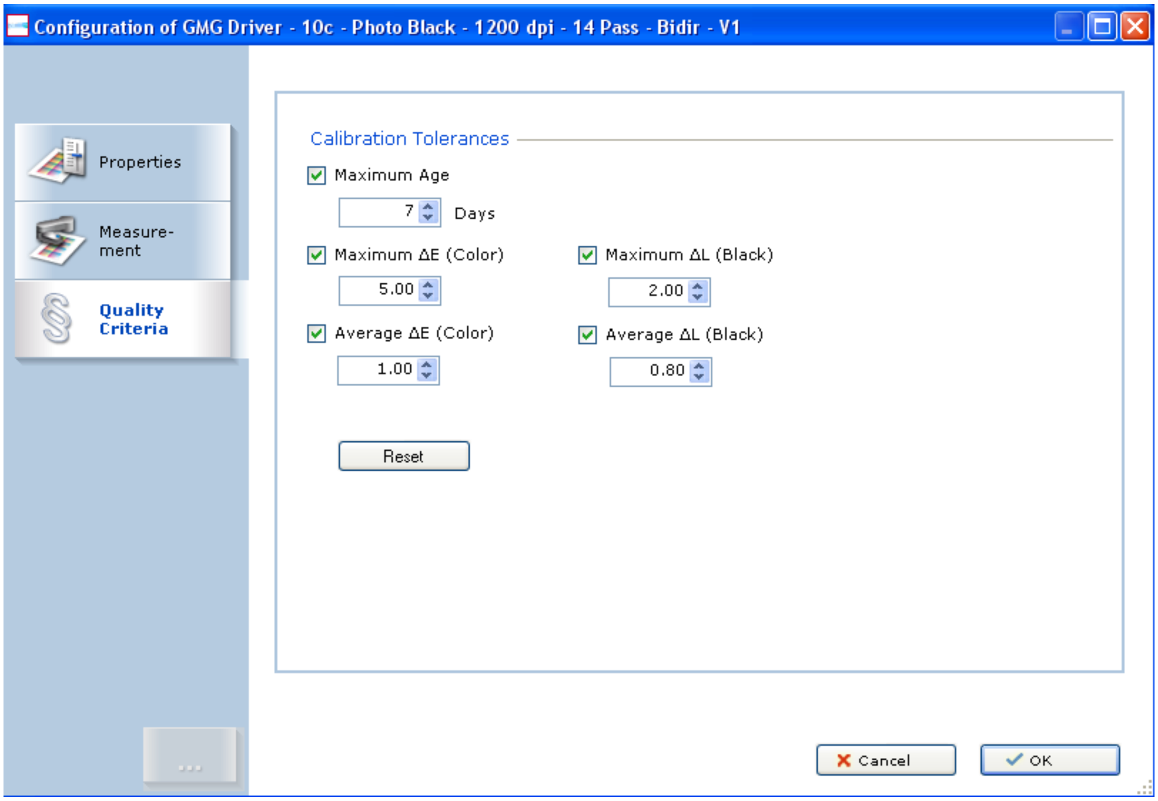


Figure C1 – Calibration setup

After the iterative process, the proofing system got calibrated. Figure C2 shows the calibration results.

Figure C3 shows the selected Job Setup for the proofing system.

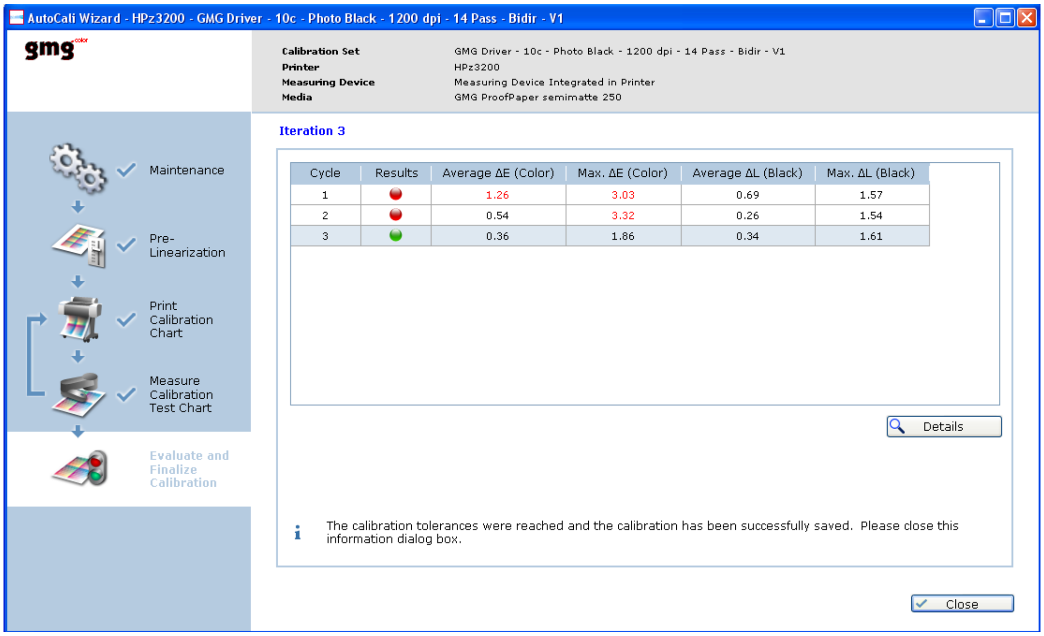


Figure C2 – Calibration Results

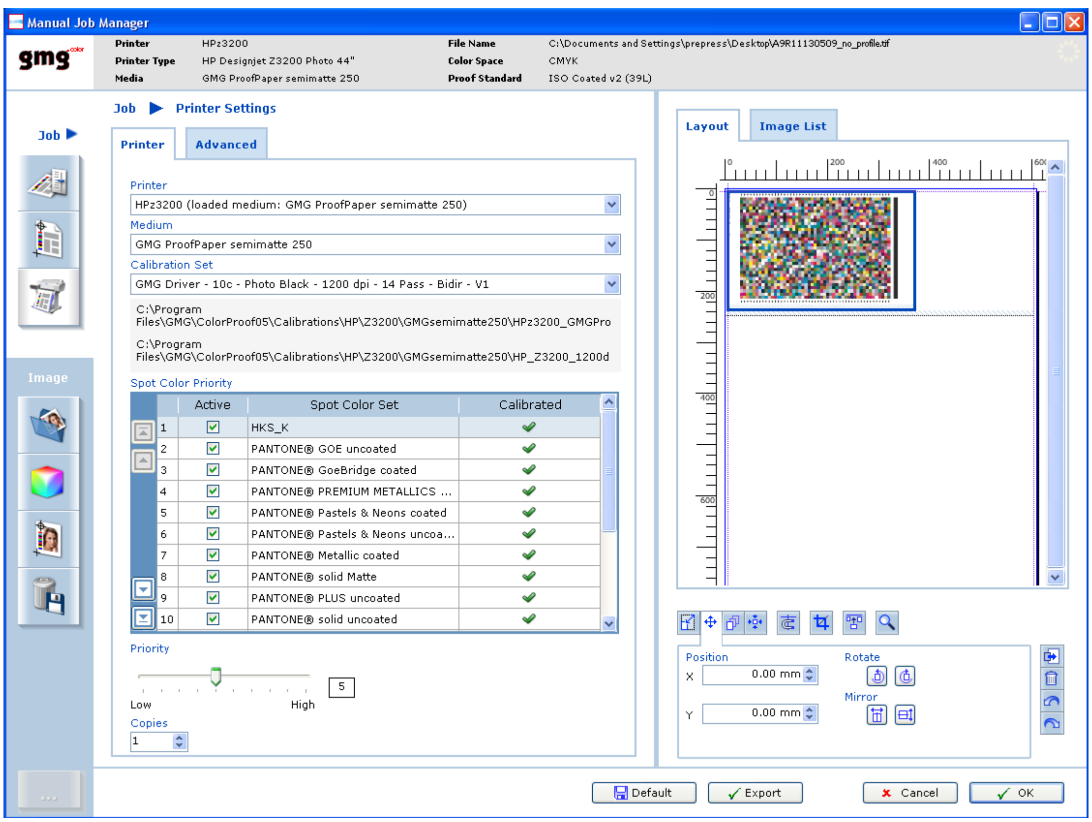


Figure C3 – Job Setup

Appendix D

Optical Brightener Compensation Software X-Rite

1. Description

   The X-Rite Optical Brightener Compensation (OBC) Software is designed to compensate for color shits in custom ICC output profiles caused by papers containing Optical Brightening Agents.

   a. Compatible with X-Rite's profiling software Profile Maker 5, measurement module Color Port and Measure Tool, and measurement instrument iSis.

2. Optical Brightening Agents and X-Rite's OBC Software

   Optical Brightening Agents (OBAs) absorb energy in the ultra violet spectrum and re-emit light in the blue area of the visible spectrum, at 440 nm. Where the human eye perceives the paper whiter and brighter, and colored images more chromatic and saturated, the measurement instrument reads a shift toward blue. Traditional Color Management Systems fix the blue-cast by compensating with yellow, which results in unwanted yellow-cast images. X-Rite's OBC Software corrects the spectral reflection measurement data. The use of X-Rite's OBC software allows the creation of more accurate proofing profiles, where the production paper's white point is simulated.

3. Methodology

X-Rite's OBC Software works in two-steps process: profiling of test forms measurements, and visual assessment of grey patches.

In the first step, a test form (e.g. IT874) is printed and measured twice using X-Rite's iSis. The light source of the first measurement has energy only above 400 nm (UVcut mode or ISO 13655 M2). In the second measurement, the test form will be illuminated only by a UV light source (energy below 400 nm), so the effect the of OBAs will be measured. The information from both measurements is used to correct for the optical brightening agents in the substrate.

Following the measurement process, the Grey Evaluation Chart (GEC) is printed using the substrate and printing conditions as step 1. The GEC is visually compared against the OBC Grey Standards in the aimed viewing condition.

An ICC profile is built using the measurements of step 1 and the grey match in step 2. The profile will be compensated for OBAs in the production paper and used to create a proof that visually matches a print on OBA loaded paper viewed under standardize light.

Appendix E

Paired Comparison Excel Template

Image ID ____________________

Name ____________________ email ____________________
Date ____________________ Time ____________________

Instruction:

1. Four samples, A, B, C, and D are involved in the paired comparison.
2. A pair, labeled as 1st and 2nd, will be presented to you randomly.
3. Please select one between the pair according to the instructions given and place a check mark in the data table below.
4. There are six pairs to be judged.

A. Raw Data

(Check One from the Pair)

1	____	1st	vs.	____	2nd
2	____	1st	vs.	____	2nd
3	____	1st	vs.	____	2nd
4	____	1st	vs.	____	2nd
5	____	1st	vs.	____	2nd
6	____	1st	vs.	____	2nd

B. Tally Count the check marks that each of the prints received.

Print	Count	Description of how the print was produced
A	0	
B	0	
C	0	
D	0	

Sum = 0 <----- It should be 6.

C. Analysis for Consistency of a Judge

Print	Row sum	Expected	$(R\text{-}E)^2$	Total	Triads
A	0	1.5	2.25	0	0
B	0	1.5	2.25		
C	0	1.5	2.25		
D	0	1.5	2.25		

Note: '0' triad indicates that the judge is consistent. '1' traid indicates that the judge has one inconsistency, etc.

D. Identifying Triads

No. of triads 0
Prints having triads: ________

Appendix F - Print A Conformance

RIT PRINT CONFORMANCE CHECK-UP

Company: RIT **Date of issurance:** 16-Feb-12 **Report No.:** Print A

Print Conditions

Screening: n/a
Press: Kodak Approval
Press calibration: TVI

Paper: Sappi Flo
Basis Wt:
Paper type: Type 1

Ink: n/a
ISO 2846 Cert? n/a
Coating: n/a

Measurement

Instrument: X-Rite i1 iSis (x2)
Conditions: M0
Backing: White
XRGA: No

Applicable Standards

Print Standard: ISO 12647-2 (Paper Type 1) **Characterization dataset:** FOGRA 39 **Substrate corrected aim?:** No

Deviation Conformance – OK Print

Test Target: IT8.7/4 **Sampling:** 1 **Averaging:** n/a

Substrate Color

Paper white	L*	a*	b*	Gloss
Aim value	95.0	0.0	-2.0	65
Tolerance (+/-)	3	2	2	5
Measurment	92.9	0.2	-0.9	n/a
Deviation	-2.1	0.2	1.1	n/a
Conformance		Yes		n/a

Primary Solid Color

Black solid	L*	a*	b*
Aim value	16.0	0.0	0.0
Tolerance (ΔE_{ab})		5.0	
Measurment	15.8	-0.1	0.5
Deviation		0.5	
Conformance		Yes	

Cyan solid	L*	a*	b*	ΔH*
Aim value	55.0	-37.0	-50.0	–
Tolerance (ΔE_{ab} ; ΔH*)		5.0		2.5
Measurment	54.2	-35.1	-46.0	–
Deviation		4.5		-0.9
Conformance		Yes		Yes

Magenta solid	L*	a*	b*	ΔH*
Aim value	48.0	74.0	-3.0	–
Tolerance (ΔE_{ab} ; ΔH*)		5.0		2.5
Measurment	49.2	71.4	-3.7	–
Deviation		2.9		-0.8
Conformance		Yes		Yes

Yellow solid	L*	a*	b*	ΔH*
Aim value	89.0	-5.0	93.0	–
Tolerance (ΔE_{ab} ; ΔH*)		5.0		2.5
Measurment	87.5	-4.8	87.8	–
Deviation		5.4		0.1
Conformance		Yes		Yes

Tone Value Increase and Mid-tone Spread

TVI 50%	K	C	M	Y
Aim value	17.0	14.3	14.3	14.3
Tolerance (+/-)		4%		
Measurment	13.7	13.1	11.9	13.8
Deviation	-3.3	-1.2	-2.4	-0.5
Conformance	Yes	Yes	Yes	Yes

TVI 80%	K	C	M	Y
Aim value	11.5	10.7	10.7	10.7
Tolerance (+/-)		3%		
Measurment	10.7	11.4	10.9	12.8
Deviation	-0.8	0.7	0.2	2.1
Conformance	Yes	Yes	Yes	Yes

Mid-tone spread	
Tolerance	5%
Deviation	1.9
Conformance	Yes

Reproduction Limits

Tone value	K	C	M	Y
2% vs. Paper	Yes	Yes	Yes	Yes
98% vs. Solid	Yes	Yes	Yes	Yes

Note: Tone reproduction limits are based on a ΔEab > 0.15

Image Positioning

Registration	C/K	M/K	Y/K	M/C	Y/C	Y/M
Tolerance (µm)			80/120			
Measurement	n/a	n/a	n/a	n/a	n/a	n/a
Conformance	n/a	n/a	n/a	n/a	n/a	n/a

Note: Non-conformance (Conformance check= No) includes measurement uncertainty.

Appendix G - Print B Conformance

Rochester Institute of Technology

School of Print Media

TR016 Assessment

OVERALL LEVEL B

Sample name: Carlos Thesis Print_B

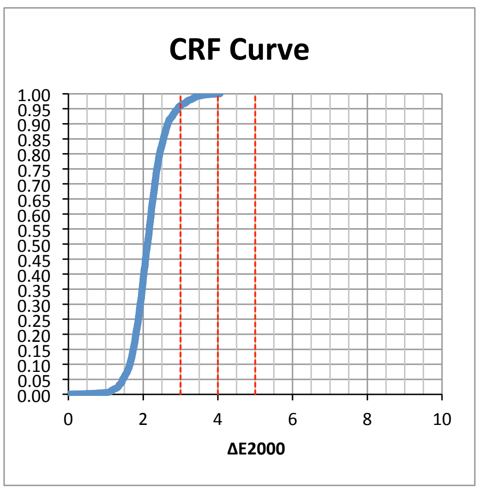
1. Table 1. Deviation metrics and tolerances

Target Description		Deviation Tolerance (ΔE00)			Measure ΔE00	Result	Weight
		A	B	C			
95th percentile ISO 12642-2		3.0	4.0	5.0	2.9	A	3
Solids	Cyan	1.5	2.4	4.0	1.6	B	2
	Magenta	1.5	2.4	4.0	2.3	B	2
	Yellow	1.5	2.4	4.0	1.7	B	2
	Black	2.4	3.6	6.0	2.7	B	2
50% input tint	Cyan	1.5	2.0	2.5	1.6	B	2
	Magenta	1.5	2.0	2.5	1.4	A	3
	Yellow	1.5	2.0	2.5	2.0	B	2
	Black	1.5	2.0	2.5	1.8	B	2
Near-neutral	50C/40M/40Y	3.0	3.5	5.0	2.63	A	3

2. Table 3 - Within-sheet metrics and tolerances

Target Description	Within-sheet variation tolerance (ΔE00			Measure	Result	Weight
95th percentile of redundant patches	A	B	C			
	1.0	1.5	3.0	0.42	A	3

3. Production variation: N/A



Appendix H – Proof 1 Conformance

PSA PROOFING CONFORMANCE ASSESSMENT

Company: Carlos Thesis **Date of issuance:** 1/24/12 **Report No.:** Alpha
Overall assessment: Pass **Date of print:** 1/24/12

Print Conditions

Test File: RIT Proofing Test File
- IT8/7.4 + 12647-7 Control Strip
- Gray Test Forms (50%, 30%, and 15%)
- ISO 12640-1: S2 & S3 (Registration)
- Font & Lint Test Form
- ISO 12640-1: S6 (Vignette)

Screening:

Paper: GMG proofing
Basis Wt: 250 g/m^2
Paper type: Semi-Matte
Proofer: HP z3200
Proof Type: Contone

Audit Measurement

Instrument: X-RIT i1 iSis (CMS Lab) Color Port
Conditions: M0
Backing: White
XRGA: Y

Applicable Standards

Standards: ISO 12647-7 **Data set:** Fogra39 **ICC profile (Source):** Coated V2

Proofing - Normative Conformance

Simulated white	L*	a*	b*
Aim value	95.0	0.0	-2.0
Measurement	94.3	-0.1	-3.4
Tolerance (ΔE)	3		
Deviation (ΔE)	**1.6**		
Conformance	Y		

Cyan solid	L*	a*	b*	ΔE	ΔH*
Aim value	55.0	-37.0	-50.0	1.1	0.9
Measurement	54.7	-36.5	-50.9		
Tolerance				5	2.5
Conformance				Y	Y

Yellow solid	L*	a*	b*	ΔE	ΔH*
Aim value	89.0	-5.0	93.2	2.5	2.4
Measurement	89.2	-7.4	93.7		
Tolerance				5	2
Conformance				Y	Y

Magenta solid	L*	a*	b*	ΔE	ΔH*
Aim value	47.9	74.1	-3.0	1.4	1.0
Measurement	47.0	74.5	-4.0		
Tolerance				5	2.5
Conformance				Y	Y

Black solid	L*	a*	b*	ΔE
Aim value	15.0	0.2	-0.1	0.3
Measurement	15.2	0.2	-0.3	
Tolerance				5
Conformance				Y

Spatial Variation 65C/50M/50Y/50K	L*	a*	b*	Max ΔE from Avg CIELAB
Tolerance (Δ)	0.5	0.5	0.5	2
Standard Deviation	0.21	0.11	0.26	0.5
Conformance	Y	Y	Y	Y

Spatial Variation 40C/30M/30Y/30K	L*	a*	b*	Max Diff from Avg CIELAB
Tolerance (Δ)	0.5	0.5	0.5	2
Standard Deviation	0.15	0.12	0.23	0.4
Conformance	Y	Y	Y	Y

Spatial Variation 20C/15M/15Y/15K	L*	a*	b*	Max ΔE from Avg CIELAB
Tolerance (Δ)	0.5	0.5	0.5	2
Standard Deviation	0.13	0.09	0.17	0.3
Conformance	Y	Y	Y	Y

ISO 12642-2	Tolerance ΔE	Measurement	Conformance
IT8.7/7 Average	4	1.84	Y
IT8.7/7 95th percentile	6	3.23	Y

Deviation of Control Strip (n=54)	Avg Error (ΔE)	Max (ΔE)
Measurement (ΔE)	**2.0**	**4.2**
Tolerance (ΔE)	3	6
Conformance	Y	Y

Deviation of Outer Gamut Colors	Average (n=226)
Measurement (ΔE)	**1.8**
Tolerance (ΔE)	4
Conformance	Y

Deviation versus near-neutrals	Near-neutral patches (C/M/Y)					
	3/2/2	10/7/7	25/19/19	50/40/40	75/66/66	100/100/100
Measurement (ΔH)	0.34	0.21	0.11	0.10	0.06	0.26
Average ΔH	0.18					
Tolerance (average ΔH)	1.5					
Conformance	Y					

Tone Value (75%)	Aim	Measured	Deviation	Tolerance	Conform
Cyan	12.6	11.7	1.0	5	Y
Yellow	12.6	13.5	-0.8	5	Y
Magenta	12.6	11.3	1.3	5	Y
Black	14.2	13.8	0.4	5	Y

Tone Value (50%)	Aim	Measure	Deviation	Tolerance	Conform
Cyan	16.0	14.3	1.7	5	Y
Yellow	16.0	15.6	0.4	5	Y
Magenta	16.0	13.1	2.8	5	Y
Black	19.6	17.6	2.0	5	Y

Reproduction of Vignettes

No easily visible steps observed on test image S6 of ISO 12640-1?	Y

Image Register & Resolving Power

Maximum deviation between image centers of 2 colors < 50 microns?	Y
Positive, non-serif, 2 point type legibly reproduced in C, M, and K?	Y
Reverse, non-serif, 8 point type legibly reproduced in C, M, and K?	Y
Reverse 2 point line legibly reproduced in C, M, and K?	Y

Margin Information

Does the proof bear a human readable commentary* line?	Y

Appendix I – Proof 2 Conformance

Rochester Institute of Technology
School of Print Media
TR016 Assessment

OVERALL LEVEL **B**

1. Table 1. Deviation metrics and tolerances

Target Description		Deviation Tolerance (ΔE00) A	B	C	Measure	Result	Weight
95th percentile ISO 12642-2		3.0	4.0	5.0	2.1	A	3
Solids	Cyan	1.5	2.4	4.0	0.4	A	3
	Magenta	1.5	2.4	4.0	0.8	A	3
	Yellow	1.5	2.4	4.0	1.1	A	3
	Black	2.4	3.6	6.0	0.9	A	3
50% input tint	Cyan	1.5	2.0	2.5	1.2	A	3
	Magenta	1.5	2.0	2.5	0.7	A	3
	Yellow	1.5	2.0	2.5	1.2	A	3
	Black	1.5	2.0	2.5	1.9	B	2
Near-neutral	50C/40M/40Y	3.0	3.5	5.0	2.3	A	3

2. Table 3 - Within-sheet metrics and tolerances

Target Description	Within-sheet variation tolerance (ΔE00) A	B	C	Measure	Result	
95th percentile of redundant patches	1.0	1.5	3.0	0.90	A	3

3. Production variation: N/A