Ryerson University Expanded Gamut Study 2019

Evaluation of Spot Color Reproduction
in Multicolor Printing

Version 2.7, 9 September, 2019

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1 Executive Summary

The Ryerson University Expanded Gamut Study 2019 is a "RoundUP" or "Shoot Out" that evaluated solutions for expanded gamut color printing from - Alwan, CGS ORIS, ColorLogic, Fiery XF, GMG Color, Heidelberg, HP, Kodak, Hybrid Software and X-Rite.

The project was proposed to vendors at an ad-hoc meeting during the Printing Industries of America Color Conference, San Diego, January 12-15, 2019 and was subsequently conducted using two, CMYKOGV printing systems - Epson SureColor P9000 inkjet printer/proofer at Ryerson University, Toronto and an HP Indigo 7900 at HP's Graphics Experience Centre, Alpharetta, GA. Printing, measurement and analysis was conducted from January - June, 2019.

While an expanded gamut system may be used for both reproduction of images and spot colors, this study focused on spot-color reproduction, in particular the reproduction of the PANTONE+ Solid Coated library.

The study consisted of a sophisticated test that evaluated the reproduction of the whole Pantone library, reproducing 1846 spot colors on the Epson P9000 and Indigo 7900 devices both using CMYKOGV inks. The study found that vendors use proprietary test charts in which the number of patches ranged from 875, the lowest number, for Alwan to 3528 (ColorLogic) and 3536 (Kodak).

A number of fundamental questions were asked, such as, do additional colorants to CMYK, such as adding Orange, Green and Violet, truly expand the color gamut? and, are color management solutions able to accurately characterize the response of CMYKOGV printing systems, the answer to both questions is - Yes!

In labels and packaging, there is a general requirement to reproduce spot colors to within a tolerance, typically < 2 DE. In this study we show that Alwan, CGS ORIS, ColorLogic, Fiery XF, GMG Color, Heidelberg and Kodak are able to reproduce more than 90% of the Pantone spot color library on the Epson P9000 inkjet printer to < 2 CIEDE2000.

In addition to the technical tests, we conducted a product review of the features and technical functionality of each system, there are some excellent products in this area, but there are also some obsolete software features that should be addressed such as using OBA correction instead of M1/M2 measurement modes or making separate "proofer" and "separation" ICC profiles.

The study identified some technology challenges within the expanded gamut ecosystem, in particular with Adobe Acrobat Pro, Adobe Photoshop CC and Pantone.

2 Introduction

The objective of the Ryerson University Expanded Gamut Study is to explore the capabilities of color and workflow solutions that are designed to produce expanded gamut work.

The benefits of expanded gamut printing may include an expanded color gamut, ability to reproduce a large number of spot colors, better accuracy on press, ability to gang jobs, less ink changes and washups, environmentally friendly solutions, etc.

Today there are many hardware and software solutions readily available, for example the aptly named Kodak Spotless Software and CGS ORIS X Gamut. There are pdf color and workflow tools such as PACKZ from Hybrid Software.

There are printing solutions available such as HP Indigo 7900 digital press and inkjet proofing solutions including the Epson SureColor P-series devices. The PANTONE EXTENDED GAMUT Guide was printed with 7 colors. There are new control strips such as the Fogra MediaWedge MultiColor 7C. This study evaluates this new range of tools for expanded gamut printing.

The Ryerson University Expanded Gamut Study 2019 is a "RoundUP" or "Shoot Out" that follows the format of earlier projects such as the IPA Ink Optimization 2010 or the Idealliance Large Format Inkjet 2013 study.

While an expanded color gamut (ECG) system may be used for both reproduction of images and also spot colors, in this study, we focus on spot-color reproduction, while images and image reproduction will be considered in future iterations.

While it is understood that the majority of expanded gamut printing for packaging may be done using conventional printing systems (flexography and offset), *the use of digital multicolor systems is a very intentional choice as it separates the accuracy of a prepress system from the variability of a printing system*. In future studies the intention is to evaluate spot color accuracy on conventional printing processes.

This study explores the state-of-the-art as it relates to CMYKOGV printing and spot color reproduction. We seek to highlight the relative strengths and weakness of the systems in a constructive manner. Reviews of this nature improve our technologies and thus grow the opportunities for everybody in the expanded gamut ecosystem.

In this study, the intention is not to rank or identify "best" systems, it is not appropriate for us to make recommendations on individual proprietary systems. Our role is to provide independent, un-biased, sound technical data and performance reviews. It is left up to the end-user/future customer to review the data and make purchasing decisions that are relevant to their own requirements and priorities. We do not seek to declare the "#1 expanded gamut solution", it is however possible to help the user identify the "#1 expanded gamut solution for you".

Often end users may be wary of a new technology and also unable to distinguish between marketing hype and factual data - whose fault is that?? The end user may not have the time (or expertise) to evaluate the technical performance of complex ECG systems. In this situation, a university-led study provides non-biased, independent, reliable information and thereby creates an opportunity for more users to consider this emerging print technology.

A number of standards committees and organizations are involved in development of a standard test chart for CMYKOGV printing. The findings from this study can contribute to the ongoing development of a standard test chart, akin to the IT8.7/4 for CMYK systems.

This report provides information so that the user can begin to ask the appropriate questions as they understand the challenges and opportunities of expanded gamut, multicolor printing.

3 Participants

Below is a list of the systems evaluated in this study. Also included in the study are systems, such as the RIP/DFE, and X-Rite i1Profiler - a well known color profiling solution.

Name used in this report	Vendor product and version number	Status
Alwan	Alwan ToolBox 1.0.3 Alwan ColorHub 6.5	Paid Participant
CGS ORIS	CGS ORIS X GAMUT 2.0	Paid Participant
ColorLogic	ColorLogic ColorAnt 5.1.1 ColorLogic CoPrA 5 ColorLogic ZePrA 7.04	Paid Participant
Fiery XF	efi Fiery XF 7.1 (Command WorkStation 6.3)	RIP for Epson SureColor P9000 and itself evaluated
GMG Color	GMG OpenColor 2.2.1 GMG ColorServer 5.0	Paid Participant
Heidelberg	Heidelberg Prinect Color Toolbox 2019 v19.0 Heidelberg Prinect PDF Toolbox 2019 (Acrobat plugin)	Paid Participant
HP SmartStream	HP SmartStream Production Pro 7.1	DFE for HP Indigo 7900 and itself evaluated
Kodak	Kodak Spotless Software (KSS) 2.1 Kodak Prinergy 8.3	Paid Participant
PACKZ	Hybrid Software PACKZ 5.0 Hybrid Software PACKZView 5.0	Paid Participant (evaluated only in appropriate areas)
X-Rite	X-Rite i1Profiler 1.82	Popular, stand-alone, off the shelf profiling product

In each case the Epson P9000 RIP and Indigo 7900 DFE were used in a pass through, "No Color Management" mode, allowing each of the participating systems to send data directly to the ink heads and printing units in the print devices. However the RIP and DFE have their own built-in color management capabilities and can manage spot colors using their own lookup tables and mapping. In the case of the Fiery XF, the spot color mode was therefore tested and similarly in the case of the Indigo 7900, the HP Professional PANTONE Emulation Technology was evaluated.

4 Advisory Committee

The processes and procedures for the study have been developed with the following colleagues who form the Advisory Committee. The Committee has contributed considerable time and energies in providing assistance to all aspects of the project.

- Roger Breton, *GRAXX Inc.*, *Quebec*
- Marc Levine, *Director of Enterprise Print Quality*, *Schawk!*
- Bill Pope, *Director*, *Graphic Reproduction Excellence*, *Greif*
- John Seymour, *John The Math Guy*
- Abhay Sharma, *Ryerson University*

Abhay Sharma, Ryerson University is the author of the report, and takes responsibility for its content. The Advisory Committee have provided guidance and advice, but may not have approved every word published in this report and in fact may have a differing opinion on some topics. The Advisory Committee deserves credit for a job well done, but is not to be held accountable for errors and omissions and any comments that may be perceived as critical or negative.
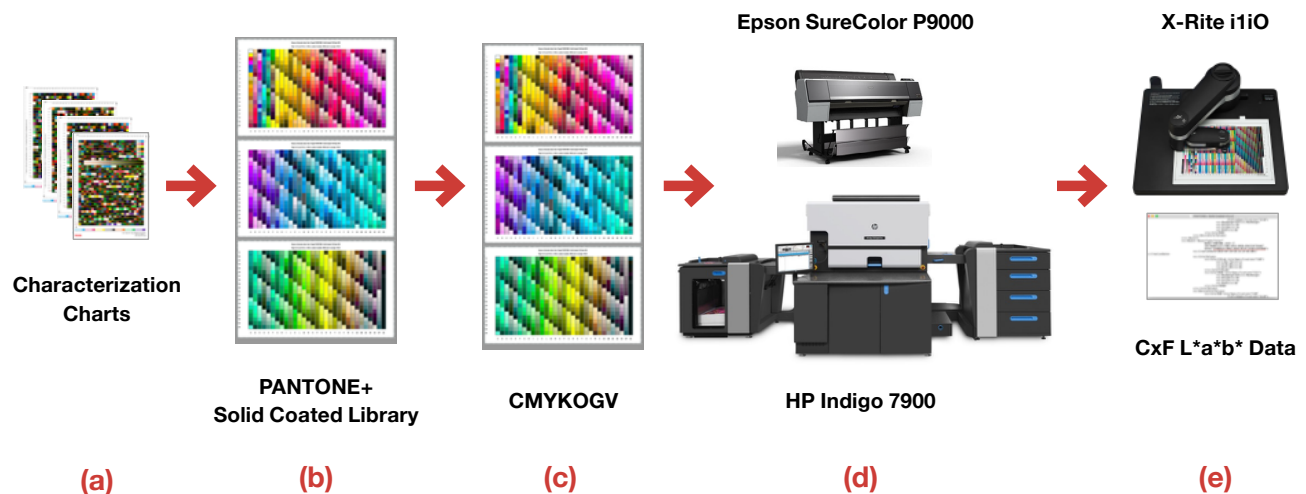
5 The Test

Figure 1: The study is based on a single, sophisticated test where after characterization, each vendor converted a pdf containing the PANTONE+ Solid Coated library into CMYKOGV values that were printed on the Epson P9000 and Indigo 7900, and measured using the i1iO and compared to target values in a CxF reference file.

The study consisted of a single, elegant test, using two digital printing technologies, Figure 1.

Two printing devices, Epson SureColor P9000 and HP Indigo 7900, using CMYKOGV inksets, were calibrated according to established practices and manufacturer's instructions. For the case of the inkjet proofer, this involved ink limiting, TAC constraints, light ink mixing, etc. The Indigo 7900 was calibrated by the manufacturer at their facility in Alpharetta.

Each software vendor characterized the printers by providing a proprietary characterization chart of their choosing, Figure 1(a). There was no restriction on the size or number of pages of the chart, only that it should be formatted for the i1iO table. The test chart from each vendor was printed and measured by Ryerson University. A "No Color Management" print mode was used for both print devices. M1 measurement mode was used. (Iteration on the characterization was allowed, but nobody used it, iteration on individual spot colors was not allowed.)

The characterization data was provided back to the vendors who analyzed the colorimetric information and created a lookup table or ICC profile, from which they created a recipe for each spot color. 1846 spot colors making the PANTONE+ Solid Coated library were formatted into a pdf file, Figure 1(b). The pdf file was processed by each vendor and the spot color channels in the file were converted into CMYKOGV inking values, appropriate for each device Figure 1(c). The CMYKOGV pdf file was returned to Ryerson University and printed on the respective print devices, Figure 1(d).

In the final step, Figure 1(e), CIEDE2000 color difference was computed between the measured value of each patch and the reference L*a*b* value from the file "PANTONE+ Solid Coated-V3. cxf". The M2-version of the PANTONE library was used as a reference as this is currently used in Photoshop CC. The CxF reference file was made available to vendors, and it was expected that vendors would load and use this as their "target".

In addition to this technical test, there was a software review which was a product review of the features and technical functionality of each system. Each vendor presented a 1-hour webinar to the committee, which was recorded, and from which the UI and general look and feel of the product was evaluated.

6 Test Outcomes

The study consisted of a single technical test, from which there are a number of relevant outcomes.

Accuracy. The research question is very simple, here is a CMYKOGV printing system, what is the accuracy with which it can be profiled (characterized)? The reader should not confuse the issue with ideas such as proofing, press proof, input profiles, reference printing conditions, etc. The simple question here is, can vendors accurately characterize a CMYKOGV, multicolor printing system to the same accuracy that we have come to expect from traditional CMYK color management. Does color management work for CMYKOGV and what is the accuracy we can expect from today's color management solutions?

Expanded Gamut. Of great interest in expanded gamut printing is the physical gamut of the printing system that is based on the inks, the media and all other aspects of the printing system. There is interest in confirming the absolute gamut of the printing systems, in other words - to what extent do the added OGV colorants truly expand the color gamut? And then there is interest in confirming if color management software can correctly determine/ascertain the full extent of the available gamut.

Color Model. When a vendor is presented with sampled device data, they use an algorithm to create a mathematical description of the device's color behaviour. Each vendor seeks to model how the inks mix and develops mathematical descriptions of the device's color characteristics. The vendor then predicts the accuracy with which they can reproduce a color. It is very informative to compare the vendor's theoretical prediction to physical samples that are printed and measured. It is very revealing to see if

vendors achieve different results when mapping the Epson P9000 compared to the Indigo 7900. It is interesting to evaluate how well a vendor understands the characteristics of CMYKOGV devices and the devices in this test.

PANTONE Spot Colors. In labels and packaging, there is the requirement to know the percentage (and names) of spot colors that can be reproduced to within some tolerance, typically < 2 DE. This test gives us those numbers. The test is able to make statements such as more than 90% of the PANTONE+ Solid Coated library can be reproduced on an Epson P9000 printer. The test provides hard data to claims often used in marketing material.

Number of Patches. Today, in expanded gamut printing there is no standard or specification for the test chart, so vendors must develop their own proprietary charts and patch values. The number of patches in the chart is of relevance to the real estate on printing systems (applications may include narrow-web flexo) and measuring instruments. The number of patches in the test chart can vary from 875, to many times that. This test records the number of patches each vendor uses to see if there is a correlation between increased number of patches and accuracy of the vendor's transform, is there an optimum number and configuration?

Ink Build. There are many different combinations that can make the same color in CMYKOGV printing. The benefits of a multicolor printing system may be better press stability through appropriate choice of colorants in a given ink build. Do some builds provide better stability on press, and do some builds provide for lower ink consumption? This test allows us to analyze each vendor's approach taken to create separations for the chosen printing systems.

Press Variability. Control strips were used to evaluate the stability of the chosen printing systems between test chart measurement and processing of the print job. From this test we get a valid data point, how variable is an Epson P9000 (a very slow proofer), how variable is an Indigo 7900 (operating at production speeds), and how do they compare to one another.

Software Review. The technical data answers all of the above questions, however, a human being, often un-skilled, needs to use the software, so in addition to the technical tests, we conducted a software review analyzing the features and UI of each system. Together the technical tests and the software review provide a 360° view of the studied solutions.

7 Rules and Regulations

The program cost was US$1500 to each participating vendor, invoiced and contracted via Ryerson University's Office of Research and Innovation.

The results are presented in a seminar - *Expanded Gamut Printing - Real Systems, Real Results* - in the Learning Experience seminar program during PRINT 19, October 3-5, 2019, at McCormick Place, Chicago, IL and at COLOR20, Printing Industries of America, San Diego, January 11-14, 2020. Numerous other publications and presentations were conducted.

The results are available as a free White Paper - *Ryerson University Expanded Gamut Study 2019 - Evaluation of Spot Color Reproduction in Multicolor Printing*. https://tinyurl.com/ExpandedGamut

A criterion of participation is that all systems must be commercially available to an end user at the time of testing. While R&D departments

or the head office may determine settings and process files or provide advice, the software products and functionality must be readily available to a customer today.

A single product configuration should be used for all tests, it is not allowed to use, for example, v2.4 for one test and v2.5 for another. Vendors must enter all tests that the system can perform, it is not possible to pick and choose between the different tests.

Vendors are unable to retract data that is not ideal from their point of view or discard unfavorable data from the suite of results. Vendors are not allowed to withdraw from the testing after the study has begun.

All measurement data and results from each vendor can be shared privately with the respective vendor. Data and results will not be shared between vendors.

8 Who is not part of the study?

Every major supplier was contacted and invited to participate via repeated e-mail requests and phone calls. Attempts were made to contact individuals at various levels within relevant organizations to lobby for participation. Meetings were held at trade shows. We reached out in particular to Esko and also contacted Agfa, Onyx Graphics, Fujifilm, Man Roland and ColorGATE. We were unable to secure participation from these vendors. If your preferred system was not evaluated, please contact your company representative and ask them to consider participation in future studies of this nature.

9 Issues with Adobe

Adobe offers some challenges when working with multicolor files using the APPE, Acrobat Pro and Photoshop.

The Adobe PDF Print Engine (APPE) is used as the color processing engine in many of today's color server products. There is a limit on the number of color channels APPE can output at once. While this limit may have been increased in more recent versions of APPE, products with custom processing that configure APPE to emit all page spots can still encounter the limit, given a page with a sufficiently large number of spots. In this testing we saw instances where color management products, based on the APPE, would not process our test file that contained 1800 spot color channels. We provided our test file to Adobe, who report that "vanilla" APPE (not part of a vendor product) successfully processed the test file, converting all of its spots to 7-channel CMYKOGV output.

When using a file with a large number of spot channels in Acrobat Pro, in Tools>Print Production>Output Preview only the first ~30 spot color names are displayed. The remainder spot channels in file are not discarded, but are shown to the user as CMYK equivalents, creating an extremely confusing situation. This was brought to Adobe's attention who have responded to this issue and have registered a high severity / high priority bug with the Acrobat engineering team.

There are a number of well-known issues with Adobe Photoshop CC. Photoshop can now open and assign multicolor ICC profiles, however the display of spot colors and spot color tints is not color accurate to the screen. Photoshop does not use any decimal points when displaying a L*a*b* value. Photoshop uses the M2 library for PANTONE values, which is a UV-cut mode,

when it is preferable to use M1 today. Photoshop keeps up to date via Adobe Creative Cloud, but its updates do not include the PANTONE digital libraries, adding to the confusion caused by the simultaneous existence of different spot color libraries with different spot color entries - a user can search for a spot color and not find it.

Recent press releases from Adobe say that their products are ready for multicolor printing, but Adobe must address the above issues before that statement is valid.

10 Issues with X-Rite/Pantone

The Pantone swatch books and digital libraries have long been a source of confusion, with different versions, variation in swatch books and different values being used. This confusion continues to plague us in the current study.

A $99 user application called the PANTONE Color Manager was used in this study to export a digital library as a CxF file. But the CxF file created from the PANTONE Color Manager has a different number of entries and different

L*a*b* values compared to the digital library provided directly to vendors under their licence agreement.

The file from Color Manager contains 1846 spot colors for the PANTONE+ Solid Coated library, while the same library distributed and used within vendor systems contains 1867 values. (The difference is due the fact that one library is based on the neon, pastel and metallic base inks in the physical Formula Guide book book while the other is not.) Another issue is that the Color Manager only provides M2 data and not M1, but it does not label the file indicating which dataset is being provided. The primary function of the Color Manager is for a user to keep their digital libraries up to date, but the program itself has a bug where a progress indicator appears to never complete its own update, leaving the user to wonder if an update has been completed or not.

The L*a*b* values in the digital library from Color Manager differ from the values in the digital library supplied to licenced vendors. As an example consider PANTONE 548 C as shown below. The two libraries have values that are different for each of the L*, a*, and b* values.

PANTONE 548 C	L*	a*	b*
PANTONE Color Manager (public application)	21.13	-20.45	-17.74
Digital library supplied to vendors under licence	21.12	-20.57	-17.76

An important development in expanded gamut printing is the latest swatch book - PANTONE EXPANDED GAMUT Coated Guide, however the measurements and data are provided in M0 mode, despite, in the same paragraph, the following wording "...the paper stock contains optical brighteners." For all measurements today, especially when optical brighteners are involved, it is necessary to use the M1/M2 measurement modes.

In the preceding section we describe how Photoshop uses the M2 library (instead of M1), Photoshop does not automatically update to the latest versions of the libraries, and the program does not show decimal points for L*a*b*. It is suggested that Pantone should ensure that all licensees of their digital libraries use the libraries properly. MacDonald's, for example, would not let a franchisee serve a Big Mac with mom's best hot sauce. Pantone has full responsibility to ensure that the end user (via Photoshop) can obtain unambiguous specification of color - isn't that what the system is supposed to do?

All of these issues had to be discovered along the way, which created many time-consuming distractions during the experimental part of this study. In this research, the issues with Adobe and Pantone products had to be discovered and workarounds found. In a commercial environment, in a busy press shop with less-skilled users, these issues are likely to pose a bigger challenge. We also note that none of these products are freeware or shareware or public domain - they are all paid for applications.

In this study, X-Rite i1Profiler was tested as it is "professional color management software for the utmost in color accuracy across all devices in the color workflow…….Monitors, Projectors, Scanners and RGB/CMYK+ Printers". There were quality issues with the results from i1Profiler, and the program has misleading dialogs, such as "CIE Illuminant D65K". Reference to a white point should be either D65 or 6500K, but not both.

We know that color management is confusing to many users, X-Rite should be assisting the user in creating seamless implementation of color management and not adding to the problems.

X-Rite, Pantone, and Esko, bring together enormous resources in terms of R&D, technology, color scientists and a rich heritage of software solutions (MonacoProfiler, ProfileMaker, Barco Graphics, Purup-Eskofot), however today we see no color strategy, no integrated product development, no sharing of technologies or know-how. Esko Equinox is a widely used expanded gamut solution, while X-Rite's i1Profiler is unable to create an accurate CMYK+ profile, X-Rite is a member of the ICC, yet Esko does not make an ICC-compliant profile, X-Rite has strongly supported the ISO 13655 M1 measurement mode, however PANTONE Color Manager does not provide M1 data......
We hope that the X-Rite, Pantone, and Esko are able to provide world class color technology solutions.

11 Comment on Color Management for HP Indigo 7900

We provide some comment and observations relating to aspects of color management on the Indigo 7900, for the benefit of the reader and end user.

The Indigo 7900 is stable and repeatable thus allowing for effective color management. To be color managed, a device must exhibit the same color behaviour between the time that the characterization chart is printed, and the customer job is returned to the press - the Indigo 7900 exhibits this quality. The Indigo 7900 is a digital production press, operating at production speeds (printing much faster than

the Epson P9000), again that the process is stable and repeatable at high print speeds is important and commendable. The maximum sheet size of the Indigo 7900, as used in this study is 13 x 19" which allows for imposition of test charts so that they are printed on a single sheet, which reduces variability and increases accuracy in color management processes. In color terms, the device is "well-behaved" by which we mean that the inks mix and create colors in a regular manner that lends itself to profiling - the device's color mixing is well behaved, and the device is stable - so it can be accurately color managed.

In terms of marketing, HP should clarify for the user that when using a CMYKOGV configuration, there would be no need for individual off press spot color ink mixing, and in fact there is nowhere to put a spot color as all units on the press would be occupied, however HP continues to advertise the 7-color solution alongside the ability to use individual spot colors. HP information and collateral continue to promote their individual "off-press" spot color solutions when there is no time or cost benefit of using individual spot colors in a digital print workflow - this confuses the market in what is already a confusing area.

An urgent practical consideration relates to the media calibration for the Indigo 7900. The calibration is done only on CMYK, totally ignoring the OGV colorants in the device! The calibration patches are sparsely populated on a page making a narrow strip down the centre of the page, forcing the calibration patches to be spread over 50 printed pages, during which time there will of course be some small press deviation.

HP's SmartStream DFE for commercial print, uses a built-in spot color table called "HP Professional PANTONE Emulation Technology using HP IndiChrome Plus on-press 7-color printing". To be effective, the printing of spot color data must take into consideration the configuration and behaviour of the device being printed to - there is no indication that HP is doing this when using the PANTONE Emulation Technology. In this study HP did not allow us to publish the results from the testing of the accuracy of the PANTONE Emulation Technology conducted at their facility, so we show data from an identical machine with similar stock, produced at a commercial printer. The two results agreed with a difference of only 0.04. HP and Pantone were asked to provide the expected Delta E tolerance for the PANTONE Emulation Technology solution - what can a user expect - but did not reply to our request.

The gamut of the Indigo 7900 is smaller than the Epson P9000. The gamut of the Indigo 7900 is not able to create many purple and violet colors. There are competing requirements on colorants used in printing (light fastness, physical abrasion, flow properties, shelf life, cost, etc.) so the choice of colorants is not trivial, however it is not clear from discussions with HP, whether they are even aware of the missing purple color gamut, let alone if they have plans to address it.

Despite bringing a number of impressive color printing devices to market from the cut-sheet presses (Indigo 7900 and 12000) to web presses for packaging (Indigo 6900 and 30000), HP's solutions demonstrate no interest in the fundamental building blocks of color management. There are many glaring omissions in the very basics of color science - the media calibration does not involve all colorants, the calibration is a few patches per page spread over 50 pages, the spot color table is totally unrelated to the device under consideration, the chosen colorants are unable to attain many purples, etc. Hopefully Benny Landa does not read this report!

12 **Experimental Details**

The tests in this study were conducted using an Epson SureColor P9000 inkjet device in halftone (HT) print mode. The Epson SureColor P9000 comes in two variants, the Commercial Edition, which uses a Violet (V) cartridge while the Standard Edition uses Light Light Black (LLK) ink instead. These inks cannot be changed after purchase, users buy a Commercial Edition or Standard Edition - full stop. We used the Commercial Edition (CE).

The other device used in the project, was an HP Indigo 7900 digital, cut-sheet commercial production press. The specification of the printing systems used in this study are described below.

Printer: Epson SureColor P9000 (Commercial Edition)
Location: Ryerson University, Toronto, Canada
Media: Epson Standard Proofing Paper (240) Semimatte, 44" roll, S045114
RIP: efi Fiery XF v7.1 via Command WorkStation client 6.3
Print mode: Halftone (HT)

Printer: HP Indigo 7900
Location: HP Graphics Experience Center, Alpharetta, Atlanta, USA
Media: UltraDigital 100# Gloss Cover, 19x13", HPFG100GC
DFE: SmartStream Production Pro v7.1

The following measuring instruments were used in this study.

|	
X-Rite i1Pro2 Rev E[1]	Serial Number 1104522
X-Rite i1iO	Serial Number 28905
X-Rite iSis2 XL[2]	Serial Number 010811 Rev A 2016

Conceptually speaking, color management is being done by the participating products that considers the printers as a CMYKOGV black box, so it is necessary that the RIP/DFE of the printing systems uses no color management. Both printing systems required a "No Color Management" or "Pass-Through" print mode. A microscope was used to confirm that the systems printed direct inking instructions, in other words "clean patches", Figure 2.

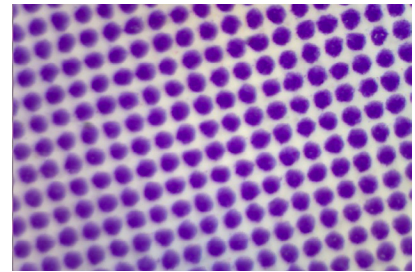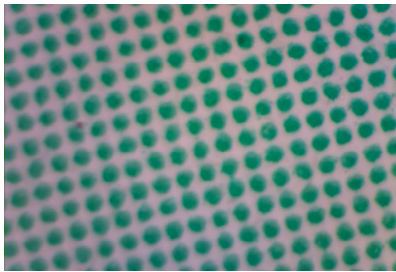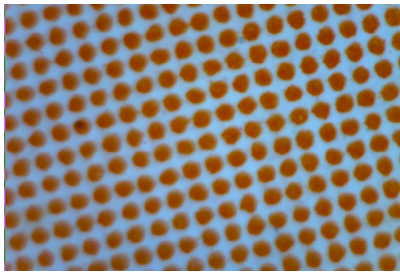[1] The i1Pro2 used was brand new, provided for the study by X-Rite.

[2] The iSis2 XL was out of calibration. It was not supposed to be part of this project but the Heidelberg entry necessitated use of this scanning instrument format, and there was no opportunity to calibrate the device.

Epson SC P9000
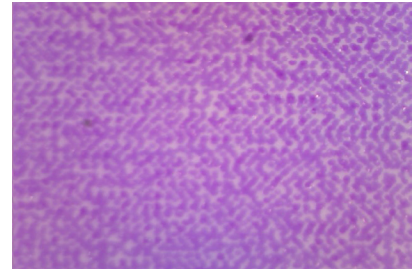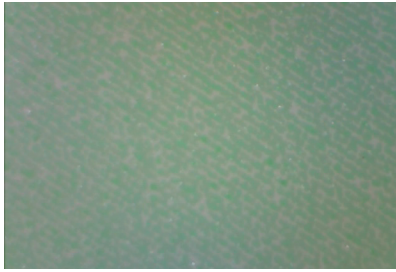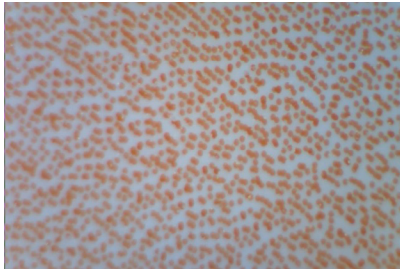
2 mm

HP Indigo 7900

2 mm

Figure 2: Output for the Epson SureColor P9000 and the HP Indigo 7900 was examined under a USB microscope to confirm that printing with no color management produced "clean patches". Here we show the expanded gamut O-G-V colorants in each printing system.

The requirement for no color management is an important consideration in this study and a parameter that needed to be continuously monitored.

13 Process Control

In color management it is well know that there are a number of parameters that influence the color quality of the end result. This includes: instrument calibration, use of different instruments, substrate material consistency, printer repeatability, and many more. In reporting and calculation it is necessary to note the lighting condition setting (D50), standard observer (2°), measurement mode (M1), DE equation (CIEDE2000), etc.

The testing fully noted all these parameters and considerations. All such variables were carefully and meticulously considered and measured, with great attention to proper experimental procedure. For example control strips were used on *every single printed piece in this study*, and in addition for the HP Indigo 7900 digital press, the Fogra MediaWedge MultiColor 7C was printed in between *every printed sample*, Figure 3. A challenge in this project was that many process control tools have yet to fully support and implement the Fogra MediaWedge Multicolor 7C.
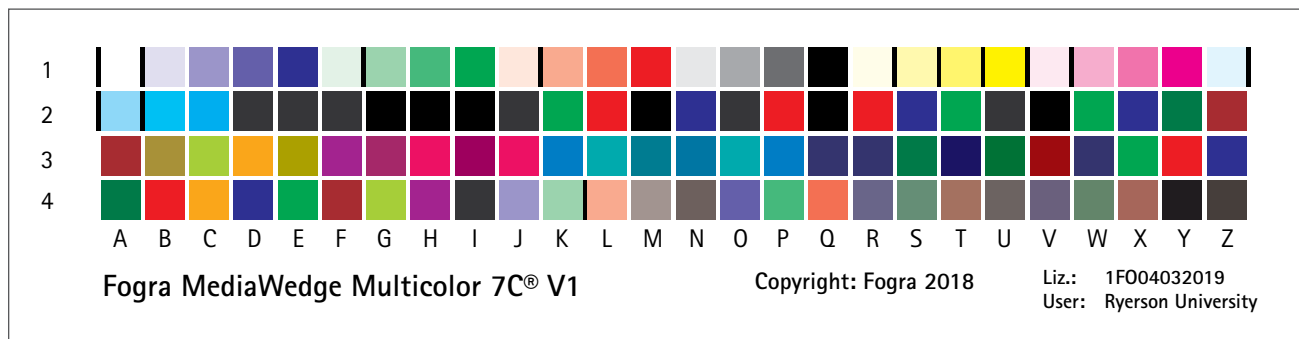

Figure 3: The new 7-channel Multicolor Fogra MediaWedge is not yet widely supported by QC applications.

A motivation to use digital printing devices in this study was to ensure that the focus could remain on the accuracy of the software systems without distraction of aspects of press variability. A pertinent question is how much variation was there between printing the characterization test chart and when the color managed job, was returned to the printing device? A color difference metric was computed to estimate press stability and experimental repeatability.

The following table shows the average color difference, for all data, between two control strips, one that was printed alongside the characterization test chart and the second that accompanied the print job. The data is based on the 3-row 84 patch Idealliance Control Strip 2013.

Idealliance Control Strip 2013	CIEDE2000 Average	CIEDE2000 Maximum
Epson SureColor P9000	0.62	1.75
HP Indigo 7900	0.85	4.26

14 Test Results

COLOR ACCURACY

The research question was very simple - what is the accuracy with which each vendor can reproduce the PANTONE+ Solid Coated library on the CMYKOGV printing systems? Delta E is a measure of color difference, so in Figure 4, we see the Delta E between expected and obtained L*a*b* values when using each vendor system. Results are presented as a bar graph with individual vendor name in alphabetical order.

In computation of CIEDE2000, the worst 5% of the data values were ignored and the lowest 95% values are averaged and reported. Removing the worst 5% is intended to ignore very high Delta E values that may have arisen from colors that were out of gamut.

From Figure 4 we see that all systems are able to achieve acceptable accuracy, with the exception of only the HP SmartStream DFE and X-Rite i1Profiler standalone profiling solution.

In general the results are more accurate for the Epson P9000 as compared to the Indigo 7900.

For every print device and vendor, there were 1846 Delta E color difference values, each one representing how close the vendor was able to come to that spot color. Ideally, these should all be near 0.0 Delta E, but the deck is stacked against the vendors. Not all of the spot colors are within the gamut of the printer. Thus, there are a number of assessments that are relevant: 1) How accurate is the vendor's color engine for colors that are within the gamut? 2) Does the vendor provide reasonable results for colors that are out of gamut? These are seemingly simple questions, but identifying whether a given spot color is in gamut is not a simple task. We seek to provide further information on this topic in a future publication.

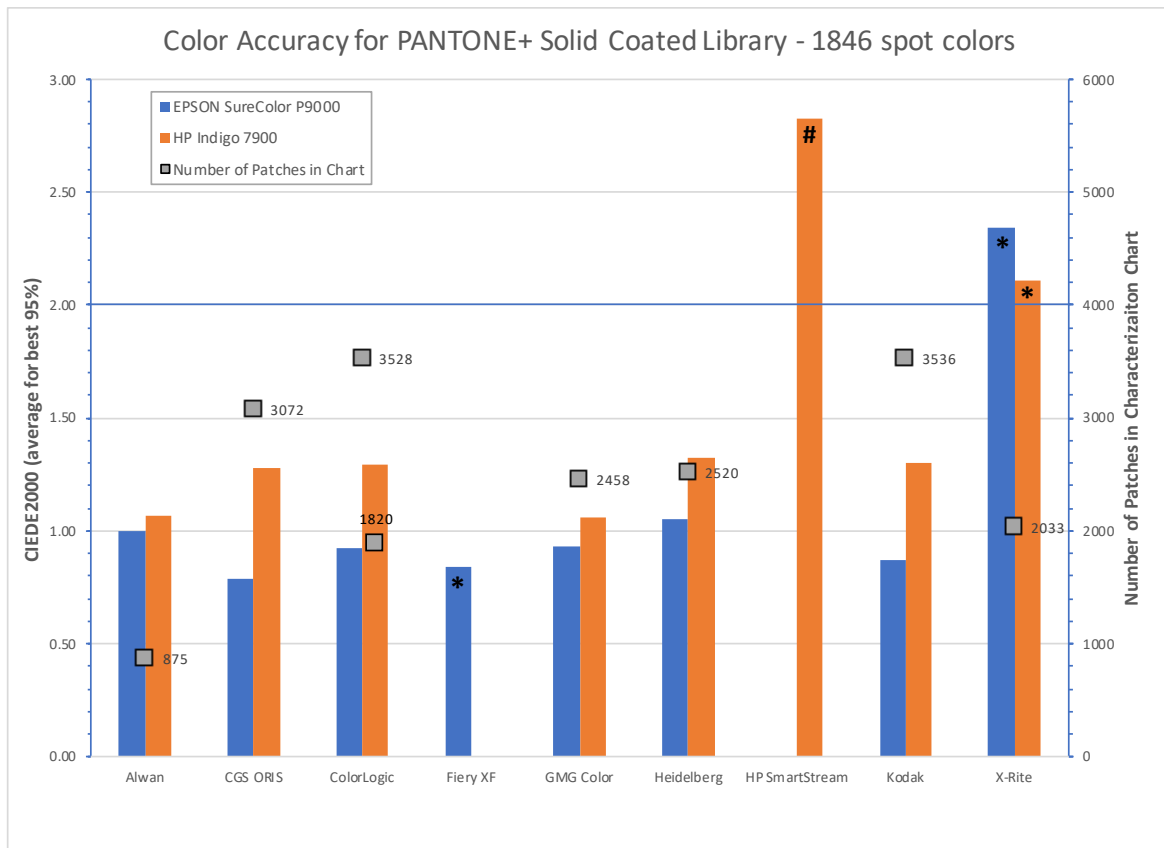Color Accuracy for PANTONE+ Solid Coated Library - 1846 spot colors

Figure 4: CIEDE2000 for 95% of the PANTONE+ Solid Coated library is presented with the name of the vendor system in alphabetical order for both the Epson P9000 and Indigo 7900. The number of patches in the test chart is indicated by a gray square.

* The results for these data points is based on 12 spot colors only.

\# This data is from an Indigo 7900 at a commercial printer and not from the manufacturer's facility.

Important Notes:
- Vendors are shown in alphabetical order.
- ColorLogic used charts with different number of patches for the Epson P9000 vs Indigo 7900, all other vendors used the same chart for both devices.
- Heidelberg's entry for the Epson P9000 was not printed by Ryerson University, but was created and submitted by the vendor, due to a technical difficulty.
- Heidelberg's entries were measured using an X-Rite iSisXL 2, as their system does not support the i1iO table.
- The entry for Kodak using the Indigo 7900 was computed against M1 values due to vendor error.

- The entry for CGS ORIS using the Indigo 7900 was computed against M0 values due to vendor error.
- Fiery XF and HP SmartStream are the RIP and DFE respectively, and do not have a characterization chart, per se.
- * Fiery XF and X-Rite entries are based on 12 spot colors only and not the full 1846 library.
- \# HP did not allow us to publish the results from the testing of the accuracy of the PANTONE Emulation Technology conducted at their facility, so we show data produced on an identical configuration, but from a commercial print shop.

The systems achieved a low (good) CIEDE2000 metric, Figure 4, which indicates that the gamut of the CMYKOGV print devices is large, the print devices are stable, the print devices are well-behaved, and the software solutions are able to properly model the device response and determine appropriate inking to create the required L*a*b* color on the substrate.

In Figure 4, two solutions have a higher CIEDE2000 - HP SmartStream and X-Rite i1Profiler. HP's SmartStream DFE for commercial print uses a static spot color table called HP Professional PANTONE Emulation Technology. To be effective, the printing of color data must take into consideration the configuration and color characteristics of the device being printed to - there is no indication that HP is doing this. HP did not allow us to publish the results from the testing of the accuracy of the PANTONE Emulation Technology conducted at their facility, so we show indicative data from an identical machine with similar substrate, produced at a commercial printer.

In looking into the results from X-Rite, it is evident that the default CMYKOGV characterization chart, with 2033 patches has a very uneven sampling of the colorspace, with most of the patches in the darker regions of the colorspace, leaving a very sparse sampling in other areas, perhaps leading to an inaccurate ICC profile of poor quality.

In general, color accuracy will depend on many factors such as the gamut of the device, variability of the printing system, repeatability of the measurement instrument, etc. But these conditions are the same for all systems, so Figure 2 can be used to evaluate the performance of the systems relative to one another. In this figure, the reader is reminded that small differences in already low Delta E values are usually not significant, especially given variations in printing and measurement.

NUMBER OF PATCHES

Figure 4 shows the number of patches in the test chart for each vendor system. The number of patches includes all patches that comprise the test chart, even if some patches are used for process control and not directly used for characterization.

The number of patches in each test chart varied from 875, the lowest number, for Alwan to 3528 (ColorLogic) and 3536 (Kodak). There is no direct correlation between high number of patches and profile accuracy when comparing vendors and solutions.

The number of patches in the chart is of relevance to the real estate on printing systems (applications may include narrow-web flexo) and measuring instruments. The study found that there is no correlation between patch numbers and quality (accuracy) of the result. In traditional CMYK characterization, the community determined a sweet spot (1617 patches), below which results were degraded and above which there was little tangible benefit. In these early days of color management for expanded gamut applications, we are still searching for the sweet spot in terms of the number of patches in the characterization test chart.

Here we are able to provide a snapshot of the industry, i.e. how many patches are different solutions using, but we are unable to make recommendations or analysis relating to an ideal patch number or patch set.

CUMULATIVE RELATIVE FREQUENCY

In another context, Figure 4 is less useful. In computation of an average Delta E, we obtained some very low numbers, e.g. 0.02 coupled with some high Delta E, such as 6 to give the averages shown. In practical printing, 6 Delta E may not be acceptable to a customer, but from the averages shown in Figure 4, the frequency of occurrence of these values is not evident.

For a better understanding of the ability of the systems in practical use, the cumulative relative frequency (CRF) is plotted for the Epson P9000, Figure 5 and for the Indigo 7900, Figure 6. As a reference, a line is drawn at CIEDE2000 = 2, which is a practical tolerance in package printing.

In analysis of the CRF graphs, Figure 5 and 6, we would like to see data that is low and stays low for the longest time. For the Epson P9000, this test shows exactly that behaviour, the systems are low (<2 CIEDE2000) and stay low until around the 90th percentile. The tests shown that the solutions are able to reproduce 89-94% of the PANTONE+ Solid Coated spot color library on the Epson P9000 inkjet printer to less than or equal to, 2 CIEDE2000. The errors at the top percentiles, where the curves rise rapidly, is due to out of gamut colors, and is expected. It is shown that the vendors have a similar ability.

The results for the HP Indigo 7900 suggest that the solutions are able to reproduce 77-87% of the PANTONE+ Solid Coated library to < 2 CIEDE2000. The lower number compared to the Epson P9000 is probably due to gamut limitations of the Indigo 7900.
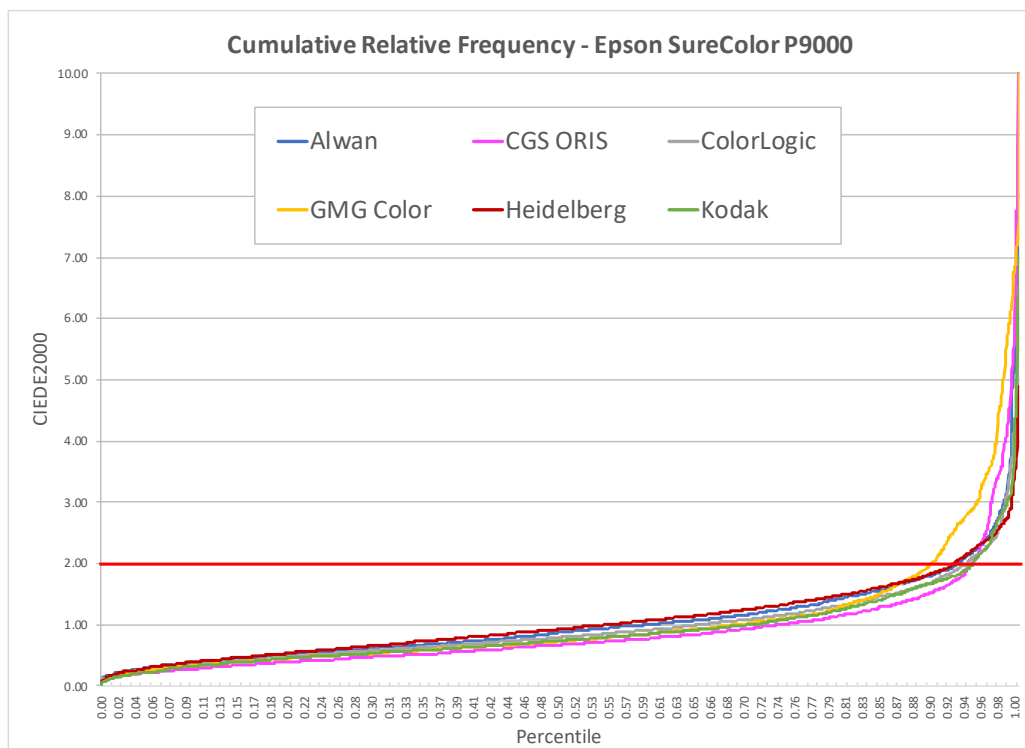

Figure 5: The cumulative relative frequency (CRF) distribution is presented for each solution for the accuracy with which the system reproduced the 1846 spot colors for the Epson P9000. This is a very good result with all systems staying "low and long".
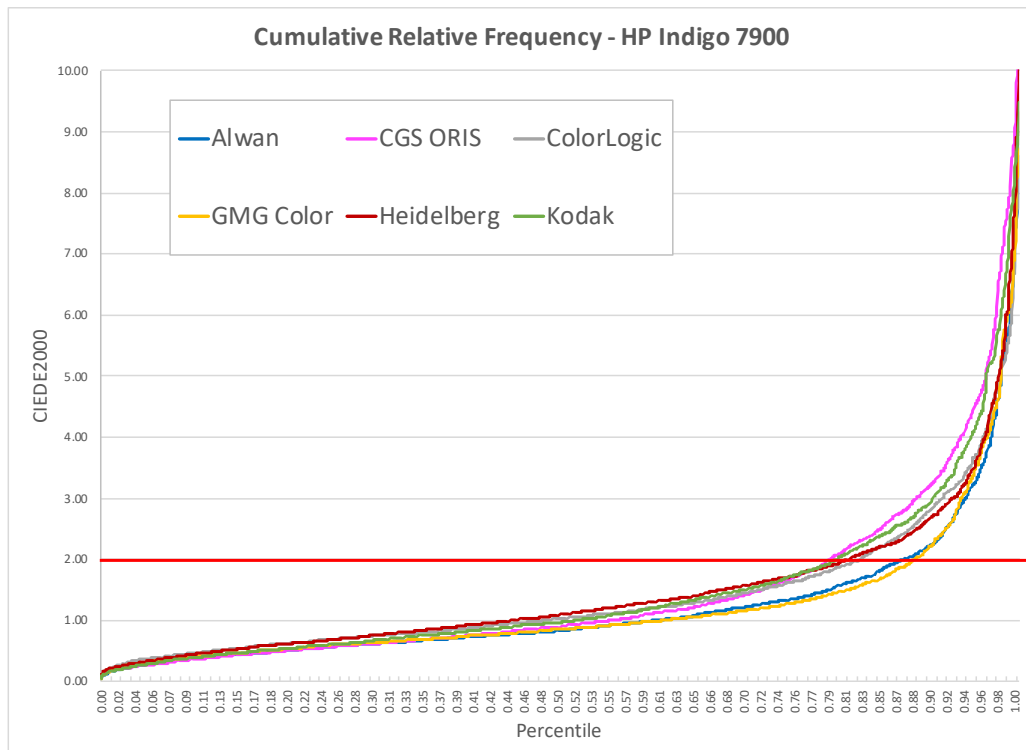
Figure 6: The cumulative relative frequency (CRF) distribution for the Indigo 7900 for the accuracy of 1846 spot colors differs between vendors. Note that due to out of gamut issues, the curves are different to the comparable data for the Epson P9000.

A practical tolerance in package printing is perhaps Delta E < 2, so the percentage of spot colors that are within this limit are recorded, Figure 7. The gamut of the Epson P9000 CMYKOGV printer allowed for a large enough gamut and the software vendors are able to properly model its response and determine appropriate inking to create the required L*a*b* printed color. *The tests prove that Alwan, CGS ORIS, ColorLogic, GMG Color, Heidelberg and Kodak are able to reproduce 89-94% of the PANTONE+ Solid Coated library on the Epson P9000 inkjet printer to DE < 2.0.* The colors that are not reproduced with an acceptable tolerance are likely to be out of gamut and therefore not physically realizable.

The results for the HP Indigo 7900 suggest that Alwan, CGS ORIS, ColorLogic, GMG Color, Heidelberg and Kodak are able to reproduce 77-87% of the PANTONE+ Solid Coated library to Delta E < 2. The lower number compared to the Epson P9000 is due to gamut limitations of the Indigo 7900 press and paper.

In all of the above discussion, the reader is reminded that small differences in already low Delta E values are not usually significant, especially given variations in printing and measuring.

Percentage of spot colors < 2.0 CIEDE2000

Legend: Epson SureColor P9000, HP Indigo 7900

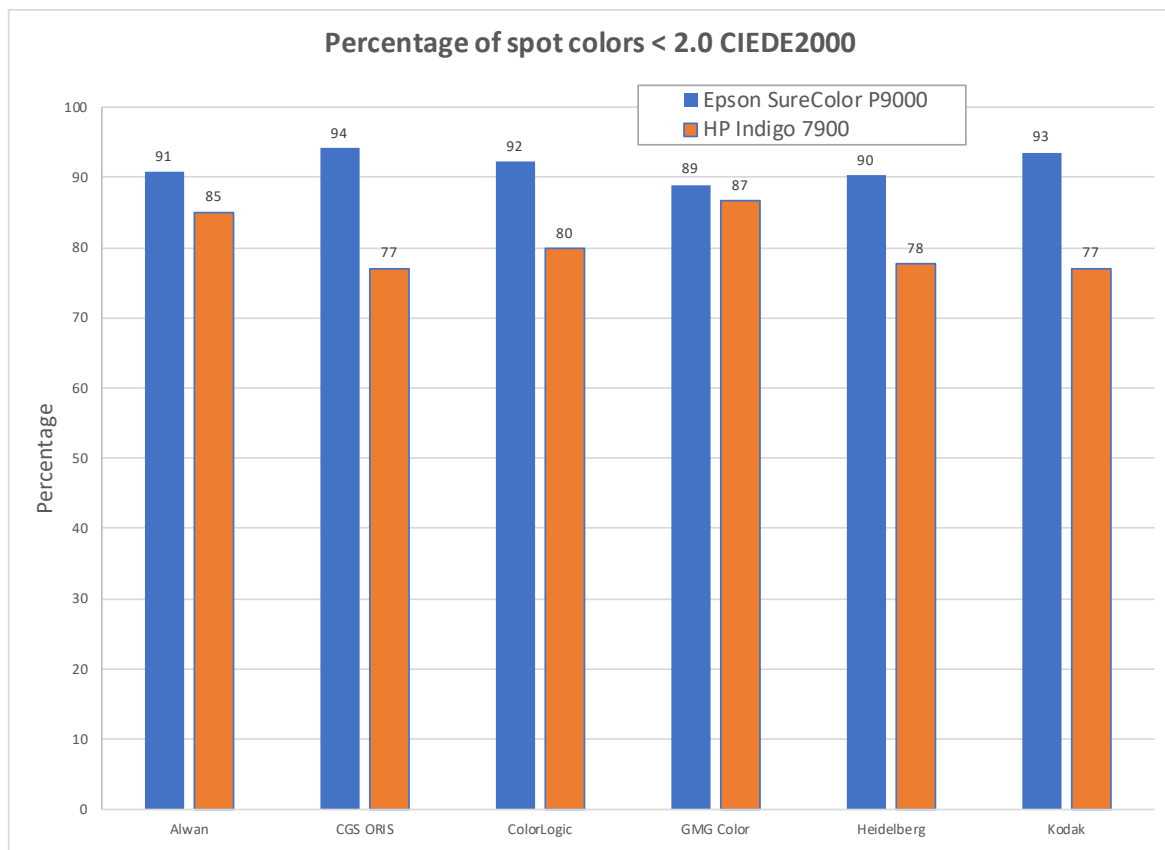|	Epson SureColor P9000	HP Indigo 7900
Alwan	91	85
CGS ORIS	94	77
ColorLogic	92	80
GMG Color	89	87
Heidelberg	90	78
Kodak	93	77

Figure 7: A practical tolerance in package printing we assume is Delta E < 2, so the percentage of spot colors that are within this limit are tabulated.

15 Ink Build

The separations and ink recipe of each system were evaluated for the Indigo 7900, Figure 8. One of the advantages of an expanded gamut system may be use of Orange, Green, and Violet. A reduction in "far away" colorants may create better stability on press, especially in transition areas of the colorspace as we move between primaries. It is possible to identify the colors that are within, say, 5° or 10°, of the hues of the mid-point between CM, MY, and CY, where perhaps the most volatility would be seen with a process color build (roughly equal amounts of each pair of process colors). PACKZ software was used to provide the inking analysis in CMYKOGV.

The addition of K creates redundancy in CMYK printing, which we use in GCR/UCR applications. Similarly, the use of CMYKOGV colorants introduces many different ways to make a color in practice. An advantage of expanded gamut printing is in press stability, it is of interest to see how the underlying color algorithm from each vendor builds those colors, for colors that are "pure" and those that near a "transition" part of the colorspace.

Alwan, CGS ORIS and ColorLogic create a very similar build, with emphasis on Orange and Yellow for what is an orange spot color, Pantone 2433, Figure 8. Kodak and GMG Color create a CMYK-only build with no expanded gamut colorants. Heidelberg appear to violate a golden rule of limiting the build to

3 channels, and uses 5 channels, but with the least TAC! It is important to note that all of the above builds returned a Delta E <1, so all of these builds create the same printed color.

These results have implications in conventional printing with respect to better stability on press, and there are implications in digital printing where each separation may incur click charges. An important initial finding is that expanded gamut printing does not necessarily equate to ink savings. Further detailed analysis is underway and will be published at a later date.
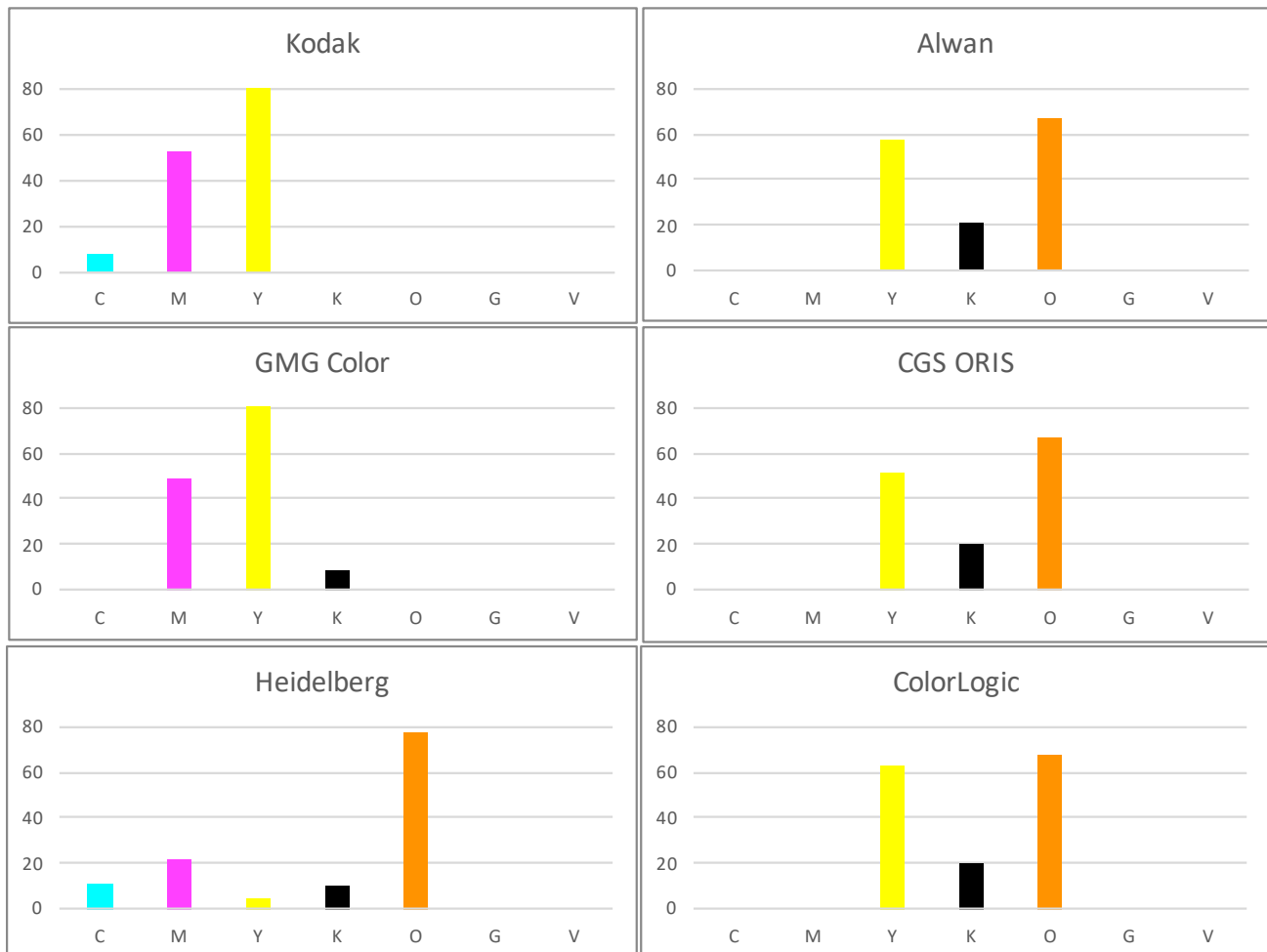

Figure 8: The CMYKOGV ink build created by each vendor for the HP Indigo 7900 was analyzed for PANTONE 2433 C - an orange color. All the above formulations resulted in a printed patch of 0.5 DE or less. Vertical, y- axis, is ink dot%.

16 Expanded Color Gamut

Figure 9: The L*a*b* measurements from all the vendor's characterization data sets, were combined to provide a visualization of the device gamut. Measurements are compared to the GRACoL 2013 gamut, clearly illustrating the gamut expansion due to the added OGV colorants. The Epson P9000 gamut has a gamut that is larger than the Indigo 7900. The Indigo 7900 exhibits "concave" behaviour between colorants and cannot create some purple spot colors. All plots are at the same scale and perspective.

In this study, we had the unique advantage of being able to combine measurement files from all the vendors to arrive at combined clouds of L*a*b* measurements, Figure 9. For the Epson SureColor P9000 inkjet printer/proofer with Epson Standard Proofing Paper we see a relatively large, complete gamut occupying all regions of the colorspace. For the HP Indigo 7900 digital press with 100# Gloss Cover media we see a slightly smaller color gamut (all diagrams in Figure 9 are at the same scale) with a reduced gamut in the purple region of the colorspace.

There are two repercussions of the missing purples in the HP Indigo color gamut. The first issue is that there will be no possibility to reproduce spot colors (or image content) that are this purple color. The second issue relates to 3-dimensional color gamut models. Most 3-dimensional color models use the concept of kitchen Saran wrap, i.e. plastic wrap is stretched over the measurement points assuming that the gamut shape is represented by a convex model and there are no inward, concave sections in the gamut. When using the stretch film approach, both visualization and analysis will overestimate the gamut extent.

The L*a*b* measurements of the Indigo 7900 represent a smaller gamut which is corroborated by earlier data analysis where we saw a smaller percentage of spot colors are reproducible to less than 2 Delta E. The smaller gamut can reproduce a smaller number of spot colors compared to the Epson P9000.

Using this data, gamut visualization issues and determination of in and out of gamut spot colors are being explored further by John Seymour and committee members, in a separate publication.

17 Special Targets for Fiery XF and X-Rite

For two systems in the study - Fiery XF and X-Rite, we used a slightly different test methodology.

The Fiery XF RIP was used to send data to the Epson P9000, and for the most part served only as the method by which we printed to the device. The RIP, however, can itself manage color and can print spot colors from an incoming document to the printer. Therefore we evaluated the ability of the Fiery XF RIP itself, and used a subset of 12 specially chosen spot colors.

For X-Rite i1Profiler, again there was no workflow to process the whole PANTONE+ Solid Coated library, so a smaller sampling of 12 spot colors were used.
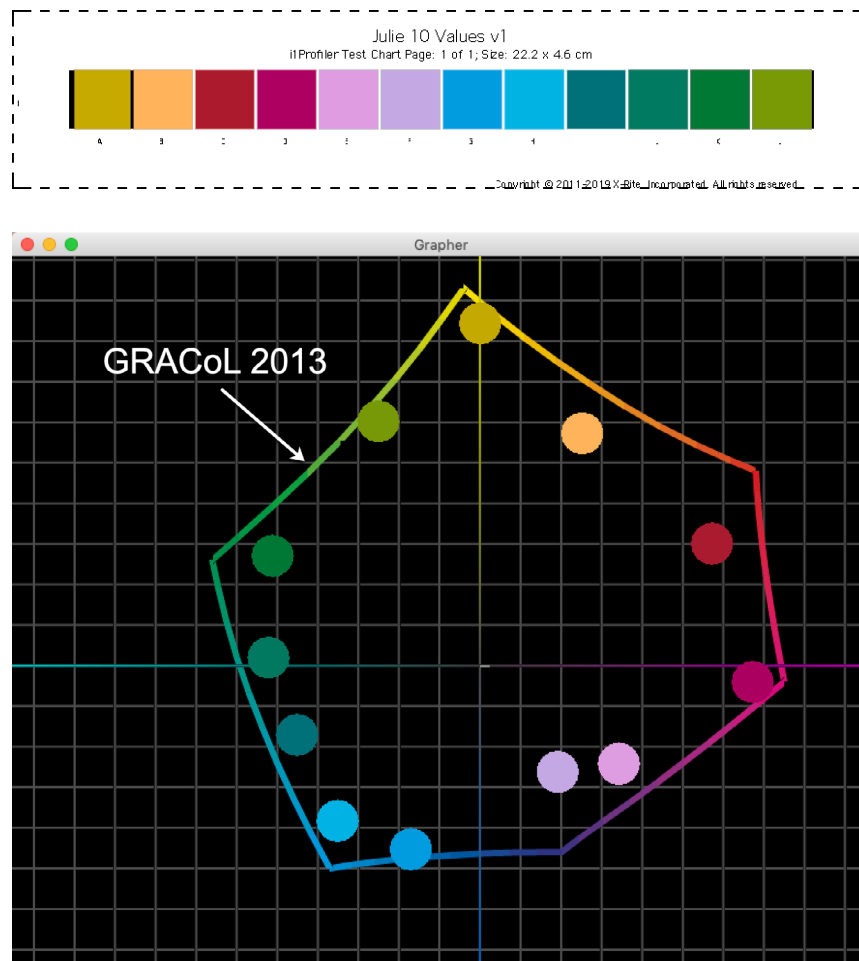
Figure 10: The 12 "Forrester Spot Colors" are at approximately L* = 50, are approximately at 30° hue angles and are within the GRACoL 2013 color gamut. They were placed in a measurable test strip.

The 12 spot colors for these systems, were determined by Julia Forrester, Ryerson University as part of her Undergraduate Student Paper for the 2019 TAGA Annual Technical Conference, Minneapolis. The "Forrester Spot Colors" are at approximately 30° hue angles and are approximately L* = 50, and are within the GRACoL 2013 color gamut. The chosen colors were placed within an image file for easy printing and measuring.

18 Product Review - Features and Functionality

This section is a "test drive" of the vendor software. We have measured the DE, examined the separations and dissected inking levels, but how does your product look and feel when driving on the open road? How does it handle, how does it accelerate, how does it take the bends? A user, reading this report will value feedback from experts who have done a test drive and provided their expert opinion. It is very onerous for a user to arrange a demonstration of all the available systems - so we do it for them. This test provides an expert's report on each product(s).

In this test, each vendor had 50 minutes to do a product demonstration to our committee. At a pre-determined time, the vendor was invited to share their screen, and present their product, via recorded Zoom session, to the committee.

The review committee consisted of Roger Breton, Marc Levine, Bill Pope, John Seymour and Abhay Sharma, and took place over June 27-28, 2019. Some vendors used slides to introduce their company then did a software demonstration, some were single-handed presentations others had a business manager make their case followed by a technical product demonstration. All vendors showed live working of their color management tools for expanded gamut printing. There was often vigorous discussion between the review committee and presenters.

Each presentation was recorded, and the recordings were later reviewed and analyzed by the committee to create the final report on the following pages. The recording was also shared with the vendor presenting.
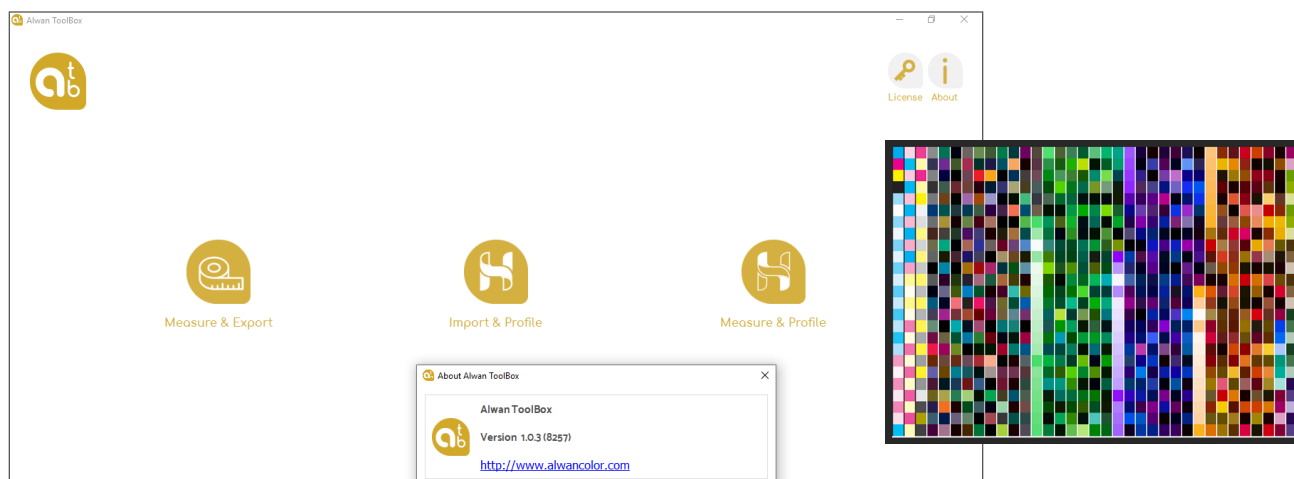
ALWAN

- Alwan ToolBox 1.0.3
- Alwan ColorHub 6.5

Overview

Alwan is a French company closely associated with its charismatic founder, Elie Khoury. Separate from their company interests, Alwan is a leader in international standards committees and working groups. In this study, Alwan ToolBox was used to measure a "Hydra" characterization chart. Hydra is Alwan's underlying spectral prediction technology used for their spectral profiling. After creation, profiles are processed using hot folders in Alwan ColorHub, a pdf color server. The workflow can include other functions such as ink optimization.

Multicolor Characterization

Alwan ToolBox offers a pre-defined chart for digital (and separately for conventional) multicolor characterization. The Alwan chart had the least number of patches in the whole study with a single page of 875 patches. The chart (see right) consists of CMYK only patches, CMYK overprints and then columns of green, violet and orange. Different physical layout (for example for narrow web flexo) is available on request from the vendor.

Alwan ColorHub is a powerful, queue based server and when using a multicolor inkset provides the option to vary the ink build between for example, using the output profile or minimizing TAC or giving priority to CMYK only inks. ColorHub can be setup to create a softproof, so that an sRGB or Adobe RGB PDF file can be created and viewed on a calibrated monitor - an important consideration for Adobe users who lack this ability.

Standardized Color

Alwan has gone out of its way to maintain compatibility and stay up to date with every type of standard and specification including GWG, Idealliance, Fogra, CxF, ICC, JDF, ISO 15930 PDF/X, ISO 19302 - Colour conformity of printing workflows, etc. It is impressive to see maintenance of both MacOS and Windows platforms which must be a challenge for a smaller company. All presentations to reviewers were effective and technical queries during the testing were answered and addressed promptly. Alwan has a range of excellent color products that produce high quality results, coupled with support that responded within minutes. If you are shopping for a multicolor solution, Alwan should be on your shortlist.

CGS ORIS

- CGS ORIS X GAMUT 2.0

Overview

CGS is a color management company popular for their color proofing and press matching applications, such as ORIS Press Matcher // Web. In recent years CGS has developed products for packaging and flexo prepress, and with this arrives - ORIS X GAMUT. X GAMUT is a standalone application specific for expanded gamut printing for spot colors, on digital and conventional presses. Unique in this study, X GAMUT is a single application (it is the client and server) with an interface as shown above, that does the whole process of characterization, spot color recipe creation and pdf file processing.

Multicolor Characterization

The generation of a characterization test chart has a nice UI, allowing easy selection of many common instrument configurations. The user is able to create a chart with 3000 patches, as used in this study. The wizard, however, retains the last used setting and not any intelligent vendor recommendation. A practical issue arose when it was difficult to use the i1iO to measure 3 test chart pages, which were shown together on a single screen as a tiny graphic. Later in the process, spot color editing is possible with a useful ring around "hive" diagram. X GAMUT provides a useful analysis tool, whereby a PANTONE library can be printed and measured and compared to reference values. CGS offered the use of this tool to us and it was used to generate the testing methodology for all the systems in this study.

Cumbersome User Interface

X GAMUT has many misleading messages. During chart measurement, for example, we get a message to use OBA correction, this is replaced today by ISO 13655 M1 and M2 modes. The recommendation to use DE*ab in parts of the process, instead of CIEDE2000, is worrying. The files for the program on the Windows platform are stored in many different, unrelated locations, making the system very difficult to use in practice, even the during the presentation to the review panel the vendor couldn't find the required files! *During the presentation, ORIS X GAMUT crashed when being used by the vendor, losing all work done until that point.* Today, high-end software products, used in production for live jobs, should not crash. X GAMUT does not follow a coherent or logical approach to expanded gamut color management, it appears to be an internal developer tool that was developed as a proof of concept that went directly from R&D to general release.
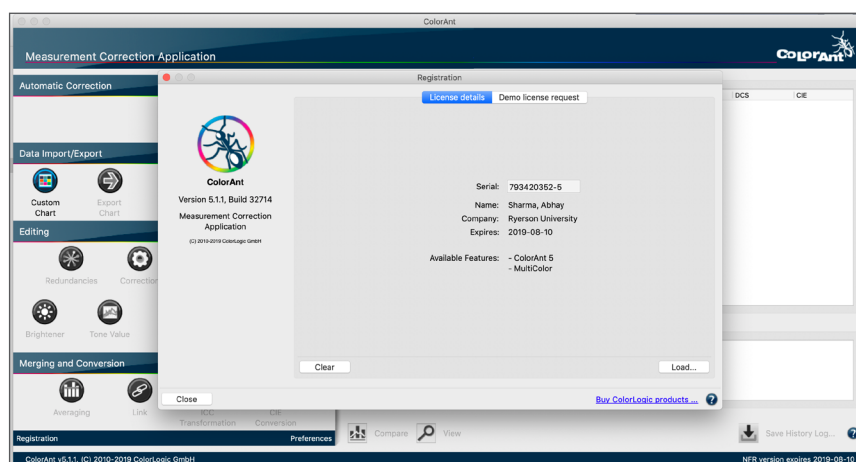
COLORLOGIC

- ColorLogic ColorAnt 5.1.1
- ColorLogic CoPrA 5
- ColorLogic ZePrA 7.04

Overview

ColorLogic has a good installed user base with a number of satisfied customers. The German company has a major US presence, with management, sales and support out of Florida. The suite of products consists of *ColorAnt* which measures, averages and smooths measurement data. *CoPrA* is used to create ICC profiles, and *ZePrA* is a color server that uses hot folders and automation, to process pdf files. The products can be used separately or together, in this testing, for example, measurement data from ColorAnt was sent using the <Transmit> function to CoPrA for profile creation.

Multicolor Characterization

ColorAnt assists the user by recommending the number of patches in a chart - Small (900), Medium (1300), Large (3300), and Custom (any). In this study, ColorLogic used specific patches to create charts of 3528 patches for the Epson P9000 and 1820 patches for the Indigo 7900. ColorAnt allows the user to analyze and correct data before moving on, the product is intuitive, keeping the color geek happy while not losing the general user. Advanced users will welcome the choices offered by CoPrA during profile generation - perceptual intent lookup table, viewing conditions, adjustment of the flexo highlight dot, etc. A relevant parameter in multi-color profiling; CoPrA allows the user to prioritize CMYK, prioritize OGV, or reduce the amount of ink.

Great Reporting

The ColorLogic suite of products provide comprehensive reports at every stage of the process - a report on the condition of the characterization data, a quality report relating to the ICC profile, and a spot color report that analyzes the reproduction of the spot color library. ColorLogic is passionate about color which shows in their products, for example, a very cool tool allows real time reduction in the number of channels and visual result of that change in a 3-D L*a*b* gamut view. Excellent context sensitive help takes you to a web page showing exactly that item, for all menus and sub-menus. ColorLogic provide a Photoshop plug-in, but sadly not for color accurate 7-color proofing, which is badly needed. ColorLogic does one thing - color, and it does it very well, it has nice icons is effective and easy to use.
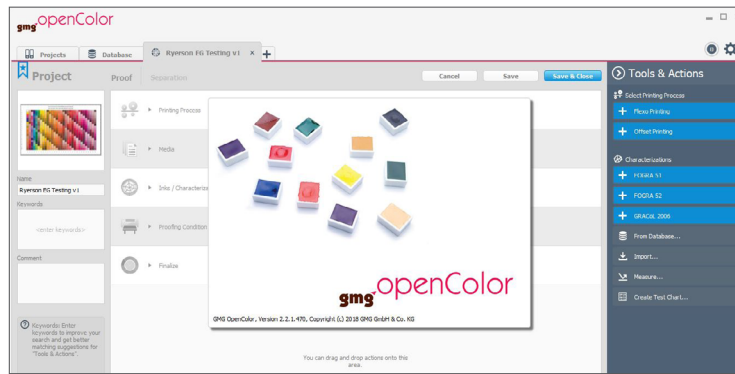
GMG COLOR

- GMG OpenColor 2.2.1
- GMG ColorServer 5.0

Overview

GMG Color provides well known color management products, with purpose built, well designed and dedicated solutions for multicolor and packaging customers. *GMG OpenColor* in combination with GMG ColorProof is able to proof directly to the Epson SureColor, although in this study we did not use this option. *GMG OpenColor* has a nice clean, modern Windows interface, with the ability to add an icon to the job for aesthetic purposes. Metadata can also be added to the job that flows through the various dialogs and enables searching and cataloguing.

Multicolor Characterization

GMG OpenColor allows a user to configure a 7-color test chart via a choice of colorants and innovative selection of screen angles. GMG OpenColor uses the target printing process to intelligently adjust the content of the test chart based on the program's understanding of different printing processes, e.g. flexography may require more patches at the highlight dot. There is however no guidance on the number of patches or a default set, users are provided full flexibility to increase the patch count and number of pages. Surprisingly a multi-page test

chart is not considered together but is measured and managed as individual items.

The program workflow insists on a proofing condition, which may be considered a legacy concept in some instances. The ICC Specification has been an ISO standard for many years now, GMG OpenColor should import and export ICC profiles. The communication between OpenColor and the server at times appeared clumsy.

Professional Support

GMG Color have developed a nice product, fully supporting all measuring instruments required in expanded gamut printing. GMG OpenColor is a deeply technical product, but the vendor has thought about how to present information and interact with the user. The interface is friendly and helpful, we suggest more guidance on the test chart generation and urgent removal of the need to establish proofing environments. The program uses knowledge about the printing process under consideration, which is a very useful feature. The presentation to the reviewers in this study was impressive, suggesting that GMG Americas has a technically competent, knowledgeable, and professional team, you can expect quality support if you invest in this system. In the color accuracy section, GMG OpenColor performed very well, which is what GMG OpenColor users in packaging and commercial markets, have come to expect.
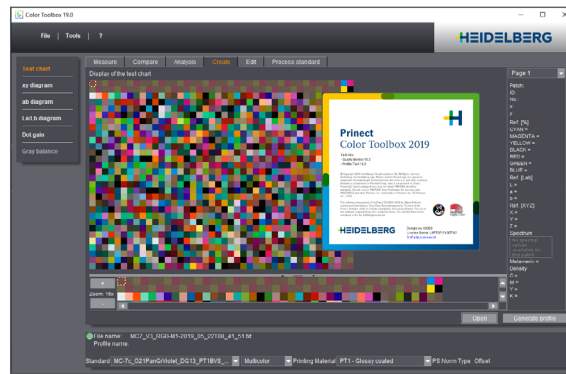
HEIDELBERG

- Prinect Color Toolbox 2019 v19
- Prinect PDF Toolbox 2019 (Acrobat plugin)

Overview

Heidelberg's color management products have an impeccable reputation and near-royal lineage. Prinect Multicolor Toolset is the umbrella name given to a suite of products that are used to create multicolor profiles and mange multicolor separations. *Prinect Color Toolbox 2019* is the program, shown above, that is used to measure a test chart and create a multicolor ICC profile. *Prinect PDF Toolbox 2019* is a plug-in to Adobe Acrobat where a spot color library is imported and spot colors in a pdf are analyzed and converted. The functionality of the PDF Toolbox is integrated/shared with a server, so that processed pdf files optionally can be returned via an internal connection to the server for imposition and workflow-based processing.
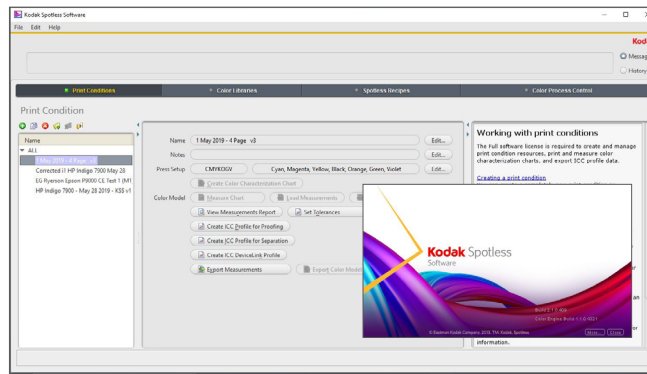
Multicolor Characterization

Installation of Color Toolbox was not easy with a GB download followed by 4 hours of technical support. Once installed, Color Toolbox has only one pre-made multicolor test chart configured for the X-Rite iSis. There is no other patch set and no other physical layout available. Color Toolbox creates an ICC profile with many useful selectable parameters

and excellent reporting. Following profile creation, the profile is applied to spot color data using PDF Toolbox. Items are confusingly labelled as "RGB", instead of "OGV".

Show Stoppers

The biggest showstopper, and inconvenience in this study, was the lack of support for the X-Rite i1iO instrument. The next issue was that the output from PDF Toolbox is wrongly interpreted by the efi Fiery XF RIP and we were unable to complete this part of the test as intended. PDF Toolbox has a poor interface more akin to a child's game. Color Toolbox was one of the most revered products in the industry and was used to create some very important datasets that are still in use today. Multicolor printing should be of strategic importance to Heidelberg given their new 7-color Primefire and Labelfire systems, yet the vendor does not appear to have a coherent strategy nor the resources for expanded gamut printing. Heidelberg's color management has the potential to return to its former glory, but the user has to work very hard to get there.

KODAK

- Kodak Spotless Software - KSS 2.1
- Kodak Prinergy 8.3

Overview

Kodak's multicolor solution is based on two products - Kodak Spotless Software (KSS), to create characterization charts and Prinergy to process pdf files using rules based automation. KSS has 4 neatly organized tabs along the top of the screen. *Print Conditions* refers to the test chart creation, printing and characterization process. *Color Libraries* is where the user points to a PANTONE or other spot color library. *Spotless Recipes* is where a spot color to CMYKOGV build is made and analyzed, and *Color Process Control*, offers control bar monitoring functionality. After all the work is done here, a datafile is handed to Prinergy to be used during processing of pdf job files.

Multicolor Characterization

Kodak reduced their test chart size during the testing from 5 to 4 pages, which is obtained via the "Use compact chart" option. The new compact chart includes G7 patches which were never measured nor analyzed. The compact chart is "one size fits all", a single chart with one set of patches, one layout, for one instrument (X-Rite i1iO) - which is extremely restrictive for most users. A target audience could be narrow web flexo and the

use of the fixed format is questionable. During a later step of spot color library verification, KSS spreads the data over 7 pages, creating an unnecessary measuring headache.

Dated Technology

Some aspects of the program are very dated, for example it is possible to create separate ICC profiles, one for proofing and one for separation. In this testing, the proofing and separation profiles were 6 MB and 8 MB, respectively. Separate profiles used to be the norm, 10-15 years ago when memory was expensive, and the data transfer was dial up. In another legacy function, KSS suggests creating characterization data from a pre-existing profile - this would not be done today because it is prone to errors and, for many years now, characterization data is stored and can be retrieved from a special profile tag. During software installation the latest PANTONE libraries are not loaded and the user must visit the Kodak Partner Place to get the latest updates. There is a bug in running the Windows program, the software continues to pretend it is new, after months of using the program it still has a warning prompt on launch "from an unknown publisher". Overall KSS has a well presented, clear interface and a logical workflow, but too many legacy constructs and not enough flexibility. For existing Kodak Prinergy customers, KSS could be where you begin your journey in expanded gamut printing.
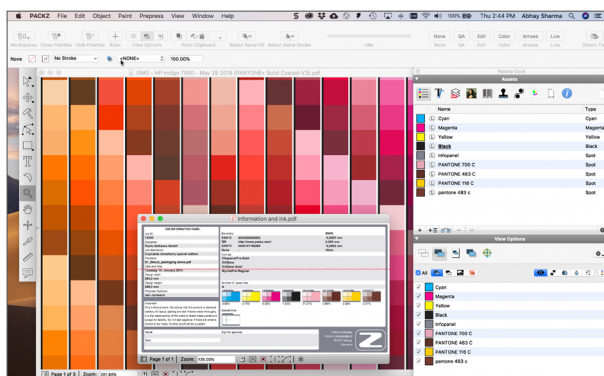
HYBRID SOFTWARE
- PACKZ 5.0
- PACKZView 5.0

Overview

PACKZ (pronounced "packs") from Hybrid Software, is a native PDF editor for packaging production - a one stop solution for packaging and label applications. PACKZ has relationships and partnerships with a number of entities such as Global Graphics, CreativeEdge and HP Indigo and in terms of multicolor technology is integrated with GMG Color. *PACKZview* is a free viewer application from the same vendor, that is similar to Adobe's Acrobat Reader.

PACKZ is a PDF editor with integrated soft proofing and color accurate display, other products can do these separately, but this is a single, powerful, native pdf editor with accurate color. PACKZ runs on macOS or Windows, and PACKZ does not have a limitation to the number of spot color channels it can display, unlike the limitations we see in Adobe Acrobat Pro. In this study PACKZ was used to analyze the ink usage for each vendor's press sheet, in practice the function can be used to estimate ink consumption for production and costing.

Multicolor Characterization

PACKZ manages color in three ways, (i) using ICC profiles and the vendor's CMM (ii) using GMG OpenColor and (iii) via a Color Book, i.e. directly from a spot color library lookup table.

In the presentation to the review committee, the vendor was unable to clearly enunciate the implementation of color management and the vendor was unable to show us the integration and operation of the GMG Color color engine. There is no methodology to edit/adjust inking values on the fly at the application level, inking values are returned from GMG OpenColor, and used as is. It appears that the dropper tool only shows device values.

PACKZ is able to display a color accurate proof of a 7-color job and PACKZ is able to display the names of 1800 spot color channels, these are two critical color management operations that are plaguing Adobe users today.

19 Summary of Software Features

	Alwan	CGS ORIS	ColorLogic	GMG Color	Heidelberg	Kodak	PACKZ
1. Can the test chart be configured by the user?	No	Yes	Yes	Yes	No	No	N/A
2. Does the vendor guide the user in choosing chart patches ?	N/A	No	Yes	No	N/A	N/A	N/A
3. Does the software offer the ability to smooth measurement data?	Yes	Yes	Yes	Yes	Yes	No	N/A
4. Can the user import customer custom CxF spot color libraries?	Yes	Yes	Yes	Yes	Yes	Yes	No
5. Can the product import/export an ICC profile?	Yes	Yes	Yes	No	Yes	Yes	N/A
6. Does the product create a separate report document?	Yes	Yes	Yes	Yes	Yes	Yes	N/A
7. Does the product offer context-sensitive help?	Yes	Yes	Yes	Yes	Yes	No	Yes
8. Can the workflow offer color accurate soft proofing?	Yes	Yes	Yes	Yes	No	No	Yes
9. Did the vendor participate in the Fogra Multicolor Forum 2018?	Yes	Yes	Yes	Yes	Yes	Yes	No
10. Is the product standalone? (Can it make a 7-color pdf without a server/workflow?)	No	Yes	No	No	Yes	No	Yes

20 What next?

This study has begun the process of quantifying and understanding spot colors in an expanded gamut system. A study of this nature in a new emerging printing technology answers many questions, but raises many more!

A future iteration for 2020 is proposed which will be an extension of the study using flexographic and offset printing systems.

Vendors may use this test to study the difference between their predicted, theoretical value and the printed, measured value. In other words, where and how does the vendor's mathematical color model deviate from the color behavior of the printing system.

The scope of the study does not include many fascinating topics such as spot color tints, CxF implementation, optimum number of patches for an expanded gamut test chart, screen angles, choice of color for the colorants, evaluation of out-of-gamut colors, ink/substrate changes, spectral matching, and many, many more interesting topics that have been brought to our attention.

For those interested in continuing the evaluation of expanded gamut printing, your attention is drawn to the *Fogra Multicolor Forum 2019*. After the successful *Multicolor Forum 2018*, Fogra have recently announced the continuation of the forum and their plans to conduct an event in 2019 - www.fogra.org/MulticolorForum2019.

21 Acknowledgments

It is a pleasure to acknowledge all vendor colleagues who have provided input and constructive critique and entered into numerous discussions via long e-mail exchanges. It is a pleasure to acknowledge the many friends we have in the vendor and color community who have worked together on this study.

We salute the bravery of the vendors that have entered this study and allowed their data to be made public and openly discussed and debated. The outcome and the results were not known beforehand, and the vendors are unable to retract data that is not ideal, from their point of view. In this environment we applaud the bravery of all vendors that participated.

A test form used in this study was created and analyzed within CGS ORIS X GAMUT. A special thanks to CGS ORIS for allowing us use of this tool that has formed the basis for this study. In addition to the participants listed above we acknowledge the support of the following partners in the project - HP who provided unlimited access and support for use of their Indigo 7900 digital press, X-Rite PANTONE who provided equipment support and advice, and Epson America who provided roll media for use on the Epson P9000 printer.

We thank Printing Industries of America, for allowing us to hold meetings during the Color Conference, San Diego, January, 2019.

The following colleagues deserve special mention for their participation in this project - A BIG THANK YOU.

Mohammed Khaled Ahmed, Mike Agness, Roy Bohnen, Roger Breton, Doug Blake, Thorsten Braun, Barbara Braun-Metz, Ray Cheydleur, Julian Fernandez, Mark Gundlach, James George, Kyle Hargrove, Jay Kelbley, Andreas Kraushaar, Henning Kramer, Elie Khoury, Marc Levine, Mark Lewiecki, William Li, Joe Marin, Paul McCarthy, John Nate, Lou Prestia, Bill Pope, David Palmieri, Birgit Plautz, Jim Ross, Mike Rottenborn, John Seymour, Mark Samworth, Mike Strickler, Cecilia Santos, Philipp Troester, Pierre Urbain, Jim Workman, Stephen Zmetana.

22 Vendor Statement and Comments (in alphabetical order)

Vendors have experience with their products and with their customer-base, and can therefore provide helpful and constructive input. With this in mind, vendors are invited to provide a general comment on the study, that is included in the final published study.

In addition to general comments and observations on the study, vendors may also provide explanation or clarification on any of the data presented in the report. The comments will be included verbatim and without any editing or rebuttal. In the past, these comments have been very useful in order to highlight good results or provide context to "not so good" results. Here is an opportunity for the vendor to reply and refute or explain, or provide context to any issues identified in the report.

ADOBE - VENDOR STATEMENT

The Adobe PDF Print Engine (APPE) is the leading rendering technology driving print production systems around the globe. It is not a product that can be directly purchased, but a Software Development Kit (SDK), which OEMs and RIP vendors integrate into their prepress workflow solutions. Today, APPE-based products dominate every industry vertical and segment: offset, flexo, gravure, inkjet, electrophotostatic, wide/narrow format, and nanographic printing. Our solution partners employ APPE to rasterize complex graphics authored in Adobe Creative Cloud and other applications. Because APPE employs the same core PDF technologies as Adobe Photoshop CC, Illustrator CC, InDesign CC and Acrobat DC, it maximizes reliability and predictability throughout most workflows, from on-screen display, to hard-proof, to the final press run.

From day 1, Adobe recognized the vital importance of digital color management for accurate print reproduction, and built it into PostScript®, our first product. Adobe color scientists were instrumental in the founding, and the ongoing work, of the International Color Consortium (ICC). Soon after Adobe invented the PDF file format, we raised the bar on color management with support for CIE-based color conversions through a Profile Connection Space (CIE 1931 XYZ). This enhancement decoupled visually perceived color from the particular gamuts of specific cameras, scanners, monitors, presses, printing conditions, and enabled a universal grammar for precisely defining, exchanging and converting colors in graphically rich content. Adobe also developed other important color innovations, such as transparency blending in PDF 1.4, and Black Point Compensation (BPC), in Photoshop version 6. Support for open standards is part of Adobe's DNA, and Adobe relinquished control of PDF to the International Standards Organization in 2008 (ISO 32000).

Spot colors are unique to print color reproduction. One of APPE's core strengths is support for dedicated color channels/separations/plates/inks beyond standard CMYK process colors, including overprinting and transparency blending. APPE also includes robust methods to emulate defined spot colors on proofers and presses with any ink set, including extended gamut sets such as CMYKOGV (Orange, Green, Violet), which is the focus of this Study. We welcome this investigation into Expanded Color Gamut printing (ECG), which has the potential to disrupt the industry, for both digital and analog reproduction. Several participating vendors in this Study include APPE-based products in their portfolio. We do not have visibility into how our partners implement APPE's capabilities in their products, which can vary widely, nor whether/how APPE was used in this Study. For example, the APPE SDK includes the Adobe Color Engine (ACE), also used to display color in Acrobat DC and CC applications such as Illustrator. However, many of our partners substitute their own Color Management Module (CMM) as a proprietary value-added component of their RIPs.

Section 9 of this Study, titled "Issues with Adobe" states that APPE has a limit on the number of output plates. This does not imply that APPE-based products are somehow limited in their support for ECG printing. There is no hard limit on colors within the input PDF file itself. Indeed, none of the Study results for participant systems which incorporate APPE were impacted by any type of spot color limitation in APPE.

This makes sense, since producing a total of 7 output colors (CMYKOGV) is well below APPE's output color ceiling. But, just to be sure, we tested the Study target file (640 spot colors/page) using "vanilla" APPE (not part of a vendor product). Current and older versions of APPE successfully processed all 1,920 spot colors in the Study test file, generating the desired ECG CMYKOGV output.

Finally, regarding the Output Preview issue discussed in section 9: Acrobat Engineering is working to raise this limit. We expect it to be resolved in an upcoming version of Acrobat.

ALWAN - VENDOR STATEMENT

Alwan Color Expertise is a worldwide leader in color management, process control and standardization software. Founded in 1997 by industry international expert Elie Khoury, Alwan develops, distributes and supports innovative software solutions allowing actors from the graphic arts industry improve margins through standards and automation.

Alwan Color Expertise offers solutions across the printing workflow, including color measurement (Alwan ToolBox), ICC profiling (Hydra Profiling®), color management (Alwan ColorHub), process control (Alwan PrintStandardizer), and quality control and reporting (Alwan PrintVerifier). Designed with the end user's expectations at heart, all these products are workflow independent and deliver cost-efficient and high-quality results. The suite

of software proposed by Alwan are compatible with all printing processes (offset, digital, flexography, gravure, etc.) and ink palettes (CMYK, spot, multicolor, etc.).

Launched in 2004 as CMYK Optimizer and renamed Alwan ColorHub in 2010, Alwan's color management server is renowned to be a pioneer in the industry, particularly since it was granted the 2008 PIA/GATF Intertech Award™ for its cutting-edge technology Dynamic DeviceLinks™. Additionally, Alwan ColorHub integrates the latest Adobe PDF Library for reliable PDF workflow. For 15 years, Alwan kept innovating and improving Alwan ColorHub to offer best-in-class ink savings and color management solutions. Ink saving capabilities come from two technologies available in Alwan ColorHub: Dynamic Maximum Black (for a stronger black channel generation than GCR) and Minimum TAC & Ink Usage (for the lowest individual and total ink consumption possible). Alwan ColorHub featured HiFi option – also known as Extended Color Gamut (ECG) – in 2012, establishing Alwan's leading position in the multicolor world. Alwan is confident that its HiFi technology, available across its suite of software, satisfies the ever-growing interest for an extended gamut and gives great results in the real world of printing.

Because experience proved that great color management isn't enough for printers to make high quality products, Alwan Color Expertise developed Alwan PrintStandardizer in 2008 to offer an automated process control solution. Stabilizing a printing process, particularly through standards, is key to get consistent quality day after day, job after job. Alwan PrintStandardizer is a powerful tool which can create dot gain curves, ICC profiles, and comprehensive reports for multiple presses and different substrates simultaneously, so press

minders, quality controllers and production managers can monitor the behavior of their presses and make sure that they match any standard worldwide (ISO, G7®, Japan Color, custom, etc.). Alike Alwan ColorHub, Alwan PrintStandardizer is suitable for CMYK, spot and multicolor (HiFi/ECG) printing to ensure consistent and accurate colors.

Alwan Color Expertise spent 5 years working on its innovative spectral profiling technology Hydra® to serve the same purpose: helping printers be more competitive through improved cost-efficiency and quality. Alwan's patented Hydra® technology has been engineered to use spectral data to build accurate 2 to 7-color ICC profiles. As a result, this ground-breaking approach requires much fewer patches that can be placed and measured even from jobs in production. For CMYK offset, only 40 patches are required to build high quality press profiles. In the multicolor digital world (CMYKOGV), only 875 patches (one A4 page) are required to build high quality ICC profiles. Hydra® multicolor chart and profiling technology have been used in this study.

Alwan Color Expertise's mission has always been to help graphic arts industry stakeholders improve margins through standards, automation and greater quality. Alwan believes that each and every part of the printing workflow, including color management, process control and quality control, is instrumental in achieving such goals. Alwan's complete suite of software reflect on this holistic approach..

CGS ORIS - VENDOR STATEMENT

CGS ORIS was happy to participate in the Expanded Gamut Study. We would like to thank Dr. Abhay Sharma and the entire committee for their time and hard work on this study.

CGS ORIS is very happy with the overall color metric results received in the study. The author unfortunately feels there are issues related to the user interface and ease of use of ORIS X Gamut. A comment made was that "ORIS X Gamut appears to be an internal developer tool that was developed as a proof of concept that went directly from R&D to general release".

CGS ORIS strongly disagrees with the authors comment and opinion of ORIS X Gamut. Our software is built off of CGS ORIS' ORIS Press Matcher software that was released in 2005 and received the PIA InterTech Technology Award in 2009. ORIS X Gamut was also awarded the European Digital Press Award in 2019 for the Best Color Management Solution category. ORIS X Gamut and ORIS Press Matcher have a proven track record in the printing industry with a very large installation base worldwide.

It should also be noted that ORIS X Gamut was chosen by the author as the software to be used to generate the testing methodology for all of the systems in this study. CGS ORIS has a difficult time understanding why the author would have chosen our software to use as a central basis of his study and then have many harsh comments and opinion-based analysis of the product.

We feel this is primarily based to the fact that CGS ORIS unfortunately did not perform well in the software demonstration portion of the study. This caused some confusion to the review committee and we feel that the harsh comments noted by the author are due to this fact but not a reflection of our products' capabilities and performance. A software crash was experienced in the demonstration which has been mentioned by the author. Readers should know that this happened due to abnormal use in the software for demonstration purposes and uncovered a bug when doing so. In further analysis CGS ORIS was able to repeat this crash and we have already fixed the issue in an updated release of ORIS X Gamut. Readers should be aware that this happened during a color management queue creation and not something that would have impacted a production environment with live jobs as inaccurately noted by the author. For the readers review CGS ORIS has published a demonstration link https://youtu.be/VLWpbg4hjLs of our ORIS X Gamut software so readers may judge our products capabilities and ease of use for themselves.

CGS ORIS feels there is always room for improvement in our software and its user friendliness. There were some UI change suggestions outlined that we are taking into account. We will use this opportunity to make appropriate changes in areas we agree our software may require improvement.

COLORLOGIC - VENDOR STATEMENT

Spot color conversion is a hot topic in the print and packaging industry as cost efficiency and quality improvement process. It is essential that our industry sees and understands the benefits of extended gamut printing when processing spot colors.

This study focussed on the reproduction of full tone spot colors without iteration. It demonstrates the 1-shot accuracy of most workflow tools. A full replacement of spot colors as process colors requires more - the prediction of gradients, overprints and transparencies. We are curious to see further studies showing the benefit of multi color printing replacing spot colors in reproduction. ColorLogic highly appreciates the effort of Ryerson University to organize this study.

The possible options by adding extended gamut printing help print and packaging companies to achieve a more standardized printing process instead of using different color sets for each job. This allows cost reduction and at the same time, implementing a more efficient, environmentally friendly process.

In addition, the necessary flexibility in print production requires color adjustments at any point of production. This is even more true for digital printing. Solutions handling spot color conversion must be flexible, easy to use and deliver the highest quality results.

ColorLogic is one of the leading providers of spot color processing technology in the industry. We handle multi-color, spot color and expanded gamut options in our complete product suite. ColorAnt, our award-winning tool to analyze and optimize measurement data,CoPrA, the ultimate ICC profiling solution for any type of output DeviceLink profiles, including tools to linearize and analyze profiles. ZePrA, our Smart Color Server rounds out our product line with

fully automatic color processing of pdf or image based files to any color space.

ZePrA's Spot Color module features the most accurate methods for converting spot colors in PDF files into CMYK, RGB or Multicolor color spaces.

ZePrA's spot color module handles the spot colors and libraries efficiently. The Spot Color Library tool allows the creation, addition, viewing, and customization of spot colors, which can be edited, imported or measured. ZePrA supports a variety of formats including Named Color ICC profiles, Photoshop ACO color tables, Adobe ASE color tables (from InDesign or Illustrator), text files in CGATS format or CxF files, such as CxF/X-4. ZePrA also provides easy access to PantoneLIVE®color libraries stored in the cloud.

ZePrA not only fully supports PantoneLIVE® but also allows our customers to use either public or private cloud-based solutions to exchange spot color libraries and ensure that each facility uses the most up-to-date libraries. Spot color libraries may also be exported to any supported file formats (CCF, ACO, ICC, TXT, CxF) to easily exchange data with any application supporting these standards.

ZePrA includes the option to convert spot colors automatically, both visually and print optimized (channel minimized). A visually optimized conversion will prioritize the lowest visual color difference based on ColorLogic's DE method. This may result in more process colors being used to simulate the spot color. Our channel reduction method prioritizes the use of as few channels as possible while maintaining a low DE 2000 value. Channels will only not be utilized if the resulting color is still close to the original spot color. Shades (or tints) of spot colors will only be printed with

those process colors, which are defined for the full tone. Also, combinations of spot colors with process or other spot colors in the files are analyzed and converted to the target color space using one of the five calculation methods.

As an add-on ColorLogic provides a Photoshop Plug-in for automatic conversion based on ZePrA. A configuration to provide 7 color preview can be set up and applied separately.

ZePrA includes the most comprehensive reporting available in the market. We believe that it is critical to know the result of the output before print. The spot color report in ZePrA shows the results achieved with spot color conversion in relation to deltaE00, deltaE76 and the process color separations. This allows the accuracy of spot color conversions to be checked and/or verified before processing or printing and determines in advance how ZePrA converts spot colors (e.g., Pantone® colors) of specific PDF and image files.

Whenever deviations occur over time due to shifts of paper, ink and the state a device was profiled, ZePrA has the option to iterate spot colors for drift or to attain even a more accurate conversion.

When iterating spot colors we measure how converted spot colors are actually printed in the current state, and subsequently optimize the deltaE2000 values. The iteration report shows which colors are improved and where restrictions based on the color gamut or the spot color calculation method occur. The report shows what color can and cannot be optimized further or limitations with the gamut or method chosen.

EFI - VENDOR STATEMENT

EFI fuels success.

We develop breakthrough technologies for the manufacturing of signage, packaging, textiles, ceramic tiles, and personalized documents, with a wide range of printers, inks, digital front ends, and a comprehensive business and production workflow suite that transforms and streamlines the entire production process, increasing your competitiveness and boosting productivity.

EFI chose not to participate in this study because it is specific to color server products which EFI does not offer at this time. But, EFI was happy to provide software and support to this project.

We realize Ryerson has a choice of RIPs to choose from and are pleased that they chose our well-established industry standard RIP: Fiery XF. XF now uses the same Command Workstation client software as Fiery cut sheet print servers, allowing for a unified print shop where operators can use the same client to drive all their production devices. Fiery XF does not simply output PDF files like a color server - it directly drives the Epson and over 800 other inkjet printers from those in design studios to grand format industrial production systems and automated cutters.

For this study Fiery XF drives the Epson in "Halftone" or HT mode. HT mode allows Fiery to have direct control of all inks independently (CMYKcmkkOVG). This allows the calibration to determine ink splitting (light and normal ink)

and independent linearization of each channel. Once calibrated the Fiery Edge profiling technology built into Fiery Color Profiler Suite can directly profile the device in its native ten-color mode including the gamut-extending inks: orange, violet, and green. Competing RIPS that use the "Contone" or CT mode are profiling the printer as a CMYK or in some cases RGB device without direct access to the inks to control and optimize the gamut expansion available with the OGV inks. Fiery-XF error diffusion screening used in HT mode delivers superior image appearance compared to competitors. Using HT mode allows XF to support more print modes at more resolutions that Epson offers with CT mode. Also, important to note is that only HT mode gives user control over the splitting of light and dark colors so that total inking can be controlled for unusual substrates that have limited inking capacity. This means XF can be used to print on these unusual substrates and some competitors cannot.

Regarding the results of the Fiery RIP – as we would expect it achieved < 1.0 ΔE00 average. This is a negligible error and is a result of the whole characterization process that is used for the media "profile" being used to create the accurate conversion. But it should be considered that only the twelve Forrester Spot Colors were used for the evaluation. Even without optimization, we believe results from Fiery XF would equal to or better when compared to the other vendors in the study if the entire PANTONE+ v.3 library was tested.

EFI is very pleased with this result. Less than 1.0 ΔE00 in a printed sample, without iteration, on the first try is the kind of precision Fiery customers demand.

GMG COLOR - VENDOR STATEMENT

GMG is a leading developer and global supplier of high-end color management software solutions, designed for all purposes and use cases. With 35 years of experience in the graphic arts industry and 150 employees worldwide, the GMG brand is synonymous with a guarantee for high-quality products, complemented by professional and knowledgeable service, consulting and support offerings. Providing state-of-the-art solutions, fit to the expectations of our wide range of customers, is what has driven GMG to call products such as GMG OpenColor into existence.

Its unique technology is based on spectral data calculation and takes parameters like printing technology or media type into account, ensuring accurate and reliable results at all times. Both proof and separation profiles can be created by measuring a mini strip or using a data base, making test charts obsolete at this stage of the workflow and profiling as simple as possible. With its user-friendly, intuitive interface and high flexibility, GMG OpenColor is fit exactly to the needs of customers working with spot colors or special conditions. In extended color gamut printing, GMG OpenColor assures an ideal color communication for any workflow, leading to stable and repeatable outputs.

HEIDELBERG - VENDOR STATEMENT

First of all Heidelberg would like to thank the Ryerson University and the committee for the significant efforts in testing the available multicolor solutions on the market. It is always good and welcome to get an unbiased view from the outside as there is nothing on earth which cannot be improved.

Second we apologize for the inconvenience you had when installing the software. This is not what customers can expect from our products. The Prinect Multicolor Tool Set is part of a Prinect Production solution. The initial set-up of the Prinect system is executed by a Heidelberg technician. Online licensing including copy protection, upgrades and updates can happen instantly or managed entirely by the operator. Unfortunately, for your testing, the base system was not available which caused many of the challenges your team experienced since they had to use a manual process running on a personal laptop - fortunately not representative of the normal customer experience.

For more than a decade Heidelberg has built up its color management strategy on mini spot technology for good process reasons. Significant R&D resources and money has been put into the close loop color control based on the mini spot technology. All Heidelberg printing machines, Heidelberg color measurement devices as well as the Prinect software have been developed to support this strategic approach. Thus Heidelberg only provides mini spot based colorcharts for the Heidelberg Multicolor Tool

Set. Only for standard 4 color digital printing application Heidelberg provides colorcharts with larger spot sizes.

In internal tests of several devices of the X-Rite products which included the i1iO as well as the iSis2 it became very clear that the manufacturing stability and the ability to measure mini spot colorcharts using the iSis2 is far superior. This is true in terms of comparable measuring results over several devices as well as the customer experience when measuring the mini spot charts. Based on this experiences Heidelberg decided to focus on the x-Rite i1 iSis2 only for its Multicolor solutions. Currently the support for i1iO is not on our roadmap. The interface, which perhaps did not clearly indicate this, will be corrected to make it more obvious for the operator.

As the i1iO is a popular device especially in the US we developed the support for regular CMYK application. For strategic reason Heidelberg does not want to provide several product for different market segments but includes its entire Color Management Know How in the Prinect Color Toolbox. Thus the user sometime has devices in the menu which are not supported for certain applications. The standard Prinect application training takes care of this issue for the benefit of the customer.

Heidelberg entered the test with the information that we could use the X-Rite i1 iSis 2 for the color measurement procedures. Basically all issues described are based on the fact that the i1iO is not a supported device for Multicolor purposes.

After the early pioneers of the Heidelberg Color Management went into their well-deserved retirement Heidelberg is happy to report that a new young talented color team has been established and trained by their predecessors.

They continue the great work of the past and have already developed new technologies leading to a variety of new patents. One of which is the new ink volume based characterization of inkjet presses. For those devices it is also feasible to use more channels for a stable print. In addition we found out that restriction of process colors to only three channels unnecessary for offset devices using Heidelberg Prinect Automated Paper Stretch Compensation. For standard digital applications we continue to recommend and support the standard approach in the Prinect Color Toolbox.

This team has also developed a brand new software tool to easily generate ICC profiles for different papers in digital printing. The user interface is designed for less experienced users to help them to easily establish a good ICC profile and significantly improve digital printing quality. This product is becoming commercially available this summer with the Labelfire and the Primefire and shows the full Heidelberg commitment to further improve color management quality and usability.

Once again we appreciate your efforts and look forward working with you in the future to further improve the color management technology for our industry.

HP - VENDOR STATEMENT

HP Indigo was pleased to assist in the Expanded Gamut Study and provided access to an HP Indigo 7900 digital press at our Graphics

Experience Centre in Alpharetta, GA. As one of the few press vendors who offer CMYKOVG, we were proud to have been chosen as a benchmark print device used for your study.   The fact that the HP Indigo 7900 digital press that runs at production speeds, was compared to a proofer in a spot matching accuracy test, is a testament to Indigo capabilities.

We appreciate Dr. Abhay Sharma's investigation into this topic, however as we reviewed the various results and comments within the report, we note some factual errors and questionable interpretations and are therefore compelled to clarify with the following information.

With HP Indigo's 7 color ink stations, there is tremendous flexibility. By default, customers use 4 stations (CMYK) but can optionally expand to 7 stations which can house OVG or any of the HP Indigo specialty inks such as White, Silver, Fluorescents, Fade Resistant, Transparent, Light Inks, (Light Cyan, Light Magenta, LLK) and others. In addition, with Indigo presses, customers have the ability to pre-mix custom inks to reach almost any spot and PANTONE® color. The HP Indigo Ink Mixing System (IMS) can be used either by the PSP or have HP provide it as service to customers. The deliverable is a canister of the custom-prepared ink that can occupy any one of the 7 stations. There are several benefits to pre-mixing inks. Firstly, during printing - a pre-mixed color requires fewer printing impressions, removing the need to achieve the color through combinations of CMYKOVG hits of color and therefore economizes on printing time and cost. In addition, IMS enables customers to reach a wider color gamut, reaching up to 97% of the PANTONE book. Beyond that, HP Indigo's LEP imaging technology allows customers to have control over the number of hits per color enabling them to achieve a variety of unique effects such as tactile or even colorful metallic effects (when printing CMYK over Silver.) To date, no other digital press vendor has all of these ink capabilities.

The calibration process is done both on CMYK and OVG. 3D calibration can be done optionally in addition to the normal calibration for extra accuracy and this is evidenced by the stable and repeatable color measured with the other vendors mentioned in the report. We use an internal Spectrophotometer as opposed to densitometer giving the highest accuracy possible.

The tests were performed using a Digital Front End (DFE) that was not suitable in comparison to the other vendor solutions. The DFE for our L&P portfolio (HP Indigo 6900, 8000, 20000, 30000 digital presses) would have been a more appropriate comparison. Each press in our labels and packaging press portfolio comes bundled with the Esko color engine and is built-in and integrated with our DFE. By using the wrong DFE in the study, readers might be misled to believe that HP Indigo spot color solutions are less than accurate.

On the contrary. Beyond HP Indigo's unique OVG and inks capabilities, we have a complete color ecosystem that achieves color accuracy and consistency across presses and fleets. HP Indigo works closely with partners in the industry including Esko and PANTONE. HP Indigo presses were the world's first digital presses to be certified by Idealliance with Master Elite Level.

According to Idealliance, "*This achievement shows the significant range and performance of the HP Indigo technology, in particular their ability to achieve color spaces, hit and maintain incredibly tight tolerances. HP Indigo passing tolerances were actually significantly tighter than the parameters of the Level I.*"

HP Indigo is totally committed to color management and employs some of the finest color experts and scientists in the industry. In addition to offering the largest variety of on- and off-press color management solutions, we offer an open ecosystem that embraces third 3rd party color solutions and innovations. We are entirely customer-focused, and our prime interest is in enabling customers to succeed and grow profitable printing businesses.

HYBRID SOFTWARE

## HYBRID SOFTWARE - VENDOR STATEMENT

PACKZ is a native PDF editor used for many prepress tasks required for the production of labels and packaging. These tasks include trapping, step & repeat, barcode creation, text editing, and many other functions, but for the purposes of this study, the most important features of PACKZ are its ability to display PDF files containing a large number of spot colors, its ability to map spot and process colors to the actual inks that will be used for printing, and its ability to provide ink usage calculations for the output inks following all prepress tasks.

For this test, PACKZ was able to open the test form containing all 1846 Pantone spot colors and display each color patch using the display profile for the user's monitor. We do not claim to provide accurate soft proofing of spot colors on the monitor; there are too many downstream variables in the print process. But PACKZ renders any number of spot colors within the accuracy of the computer display. Unlike many other software tools, PACKZ can display images and linework

built with any number of inks; it is not limited to just CMYK or even to CMYKOGV.

PACKZ can convert spot colors to output inks (including 4-color or Extended Color Gamut process) in three ways: using ICC profiles, color books, or with its direct connection to GMG Open Color. PACKZ is designed to be as flexible as possible in this regard; customers can use the color management tools that they own with PACKZ, or select the tools that fit their business. Any ICC Device Link profile can be used by PACKZ, and Color Books can be used when converting data from a proprietary ink set or another color management system.

However, the interface to GMG Open Color provides the most functionality for users of PACKZ. This is a direct interface which was jointly developed by Hybrid and GMG which allows PACKZ to dynamically request a new profile for each combination of input and output colors. The profile is supplied in near real-time by GMG Open Color and applied in PACKZ. PACKZ also displays the DE resulting from the conversion to CMYKOGV. (See screen shot "PACKZ Open Color Channels and DE.png")
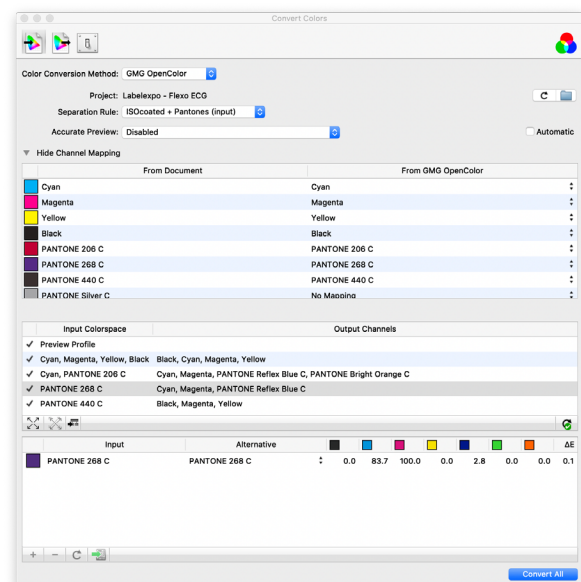
In summary, PACKZ provides the prepress tools needed to convert design files into print-ready production files, with a powerful GMG Open Color connection as well as broad compatibility with the various color management systems in use at our customers.

KODAK - VENDOR STATEMENT

Kodak combines modern color technology with decades of experience working in the graphic arts and packaging industries to deliver a solid system to enable printers and converters to implement and deliver Extended Color Gamut (ECG) printed product. We understand that industrial requirements demand industrial-strength solutions.

The core of ECG is treating all the inks which go on press as part of a single process whole. Whether that's 5, 6, or 7 colors, it's important that the workflow deal with the management of color, even as different markets require different solutions. This is the power of mass customization.

Implementing ECG on a consistent basis requires integrated solutions which work across the entire print shop, not just isolated islands of software which require extra effort to plug into existing workflows. This is clearly evidenced by the majority of the systems on the market today which recognize that a modular approach is best, one which gives users the choice to pick workflow components which are uniquely relevant to their own requirements.

Kodak Spotless Software (KSS) is designed to be capable of both integrating into Kodak as well as other content processing workflows.

In a real-world, production ECG implementation, the calculations which directly generate the recipes for converting spot colors and the ICC profiles for proofing and image separation are only the tip of the iceberg. Well before characterizing the print system, Kodak Professional Services will work with print service providers to stabilize and improve their print systems and workflow for ECG. This means not only setting up gray balance and tone value aims, but, more importantly, ensuring that systems and practices are put into place to ensure that the printing and color remain consistent from job to job. Kodak Spotless Software reinforces this consistency through web-enabled quality analysis reports which enable views of the current and past performance of any given print system implementing ECG.

We recognize that there are many different types of systems out there, which is why Kodak Spotless Software includes both modern as well as legacy compatibility features. An example of this is the ability to generate both regular ICC profiles used for both proofing and color separation as well as specialized "proofing-only" ICC profiles required for some older legacy 3rd-party systems.

After KSS generates recipes and ICC profiles, it is up to the workflow to apply this color information for production and proofing. Proofing can be done in either soft-proof form, via the Matchprint Virtual technology available inside the InSite family of products, or hard-proof via the Kodak Proofing Software, both of which are ECG-aware as we use a common color technology base throughout the entire

Kodak software platform. It is very seldom the case in industrial settings that one only wants to just look at pretty color. Features like verification, tracking, and annotation are important for proofing, which is why these functions are handled in their own packages.

In production, ECG implementation requires an industrial-strength workflow. This is something of a hidden requirement not obvious to most users. Most designers are used to working interchangeably with RGB and CMYK files during the design stage. However, the implementation of ECG in PDF in particular means that it is technically complex to do conversions into ECG, as PDF itself has limited support for ECG as compared with CMYK. The Prinergy workflow handles all of these conversions sight unseen in a fully automatic manner which looks no different than setting up a CMYK conversion workflow.

Delivering ECG on an industrial basis requires industrial tools.

X-RITE/PANTONE - VENDOR STATEMENT

It should be noted that X-Rite/Pantone was not a 'full participant' in this study as noted within the Participants listing and thus not given the ability to optimize the results presented for i1Profiler. That said, the procedure used to evaluate i1Profiler differs significantly from the one used to evaluate the other solutions within the report. Specifically, the sample size of the

test colors (12 vs 1846). This is a significant disparity with respect to statistical relevance. Further, the profile was generated using default settings that are not ideal for a test of this nature. Two changes would improve performance: a larger characterization target and use of profile optimization. Both are known strategies to greatly increase accuracy and would have benefited the results had it been the 12 patches used for i1Profiler or the 1846 used for all other products. However, as indicated within the test protocol, "no iteration was used" and therefore the latter recommendation could not be employed, yet a larger test target certainly would be recommended.

With respect to Pantone color data, it was outlined within the report that this data was sourced from Pantone Color Manager (PCM). The purpose of this tool is specifically to address Pantone color libraries associated within popular design applications. For both legacy and compatibility reasons, this data is supplied in M2. There is no ability to select alternate M-Modes to avoid confusion and potentially inconsistent results for whom the tool was intended.

Also, while the desire with regard for Adobe to reference M1 data has some merit as M1 has become the de facto in various print standards, design applications continue to use M2. The inclusion of the appropriate UV content to match M1 D50 (ISO 3664:2009) can frequently not be guaranteed thus leading to inconsistent results and so forth. OEM licensees of Pantone often receive multi-mode data (M0, M1, M2, M3) for integration into their production products as that is an appropriate place for such mappings and separation to occur. Hence our recommendation to customers is to maintain spot channel identity and separate only when necessary and appropriate so proper

color management can be applied correctly and consistently.

Lastly, the need for consistency across Pantone color data provided within color management solutions was mentioned in several places. We certainly endorse that viewpoint and encourage customers to request that of their respective vendors by either updating their licensing arrangement or integrating PantoneLIVE support. Both are effective means for this ideal to be achieved.

We are excited to see the interest in ECG grow and look forward to future studies on the topic to help the collective print industry move ahead.

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