Development of a Test Suite for Digital Printing Devices

Martin Habekost*, Abhay Sharma*, Tony Lu**

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Abstract

Digital printing is becoming increasingly popular for many printers due to its ability to include shorter runs and variable data. Purchasing a digital printing device requires in-depth evaluation of print quality produced by the device. The process of evaluating digital printing devices is not standardized so the purpose of this paper is to propose an effective test suite for all digital printing devices. By using the proposed test suites, printers could make informed decisions when considering a digital printing device based on their needs. The test suite developed included the following tests: gamut volume, Pantone color matching, Pantone color clipping, Resometer from Technology Watch™, fade resistance, rub resistance and fold resistance and matching a reference printing conditions, e.g., GRACoL or SWOP. A total of nine supplier systems (eight digital printing devices and one offset) participated in this study.

After testing all the supplier systems, it was safe to conclude that that the testing suite developed truly showed the abilities of a digital printing device. In addition, it also provided a good outlook on the future of digital printing since the digital printing devices can now provide the quality and performance that is competitive to traditional offset printing. The test suite outlined in this paper is just the beginning in establishing a standard in evaluating digital print production, as further developments in digital printing could suggest more improvements to this suite in the future. Further areas of research for digital printing could include but not limited to: inkjet devices, inline or nearline finishing on digital devices and productivity (processing power, uptime and reliability).

*Ryerson University, School of Graphic Communications Management
**Ryerson University, School of Graphic Communications Management, Student

Introduction

Digital print production is becoming more pervasive due to technological advances in the past decade. Advantages of digital printing include shorter runs, custom publications and variable data printing. With so many digital printing devices on the market, it is important for printers to evaluate them in accordance to their needs. The following study is based on the IPA's Digital Print Forum [IPA, 2008] results in April 2008 where a comprehensive test suite for digital printing devices was introduced. Since digital printing is fast approaching the quality of offset printing, results from the digital printing devices will also be compared to an offset press for further analysis.

The aim of the work being presented was to determine how effective the testing suite is in evaluating print quality and characteristics. A total of nine printing devices (eight digital printing devices and one offset) were involved in this study. The testing suite developed tested the following properties: color gamut volume, reproduction of pantone colors, resolution-contrast, addressability, dot gain, ink trap, fade resistance, rub resistance, fold/crease resistance, and deinking/recyclability. The testing of samples was made possible with the cooperation of Rochester Institute of Technology, Western Michigan University, Ryerson University and Q-Lab Corporation.

Experiment

Supplier Systems

The following table (Table 1) lists all the printing devices used in this study. It includes the supplier name, device/hardware, list price, and digital front end (DFE). The list price (provided by suppliers) is the price for a base configuration including RIP. The Heidelberg XL 105 is the only offset lithography press while the remainders are digital presses. For all the HP digital presses, end-users and not the supplier produced the press sheets themselves. Hence, the column "Printed at" shows where those press sheets were printed.

#	Supplier	Hardware	List Price (US$)	Digital Front End (DFE)	Printed at	Substrate
1	Heidelberg	XL 105	2,900,000	N/A	-	Sappi Hannoart Gloss 80lb Text
2	HP	Indigo 3050	259,000*	Indigo RIP 5.2	Cober Printing	Spicers Supreme Gloss 80lb Digital
3	HP	Indigo 5000	349,000*	HP Press Production Manager 2.5.16	North American Color	Sappi Hannoart Gloss 80lb Text
4	HP	Indigo 5500	415,000*	HP Press Production Manager 2.6.1	Cober Printing	Spicers Supreme Gloss 80lb Digital
5	KODAK	NEXPRESS S3000	542,000	NexPress V Front End with System Software v10	-	NewPage Sterling UltraGloss 80lb Text
6	Konica-Minolta	bizhub PRO C6500	75,000	Fiery IC-303 version 1.1	-	Gloss Print 80lb IT Digital
7	Punch Graphix	Xeikon 6000	795,000	X800 version 1.8	-	130 gsm Arctic Gloss 4DI 500mm
8	Punch Graphix	Xeikon 8000	TBA	X800 version 2.0	-	130 gsm Arctic Gloss 4DI 500mm
9	Xerox	iGen3 110	580,000	Xerox FreeFlow Print Server	-	Xerox Digital Color Elite Gloss Text 120 gsm

Table 1. *List of Supplier Systems.*
**HP list price is based on a 4-color configuration*

Substrate

Table 1 also displays the substrates used for each printing device. For this study, it was agreed upon that each supplier would use the same category of paper but not necessarily the same brand or stock. Although it was possible to provide a common substrate for all devices, some printers may recommend specific paper types that they preferred. Therefore, suppliers were instructed to use a coated, gloss finish, 80lb/120g/m^2 text stock for all the tests.

Gamut Volume

The color gamut of a printing device determines how many colors it could reproduce. A "full gamut" IT8.7/4 target was printed by each supplier and was used to help compute the color gamut volume. For this test, four different methods were used to determine the gamut volume of each device. The first method involved manually measuring L*a*b* values of the CMYK, RGB and white patches. From these L*a*b* values, the color gamut was calculated using an Excel spreadsheet that calculates the volume based on the hexagonal tight sphere packing from crystallography [Paul, 1994]. The second, third and fourth methods involved using different programs to determine the color gamut with ICC profiles created from the IT8.7/4 targets. The three programs that were used for this test were: ColorThink Pro 3.0.1b20, Monaco GamutWorks 1.12, and Gamutvision 1.37.

Pantone® Colors I

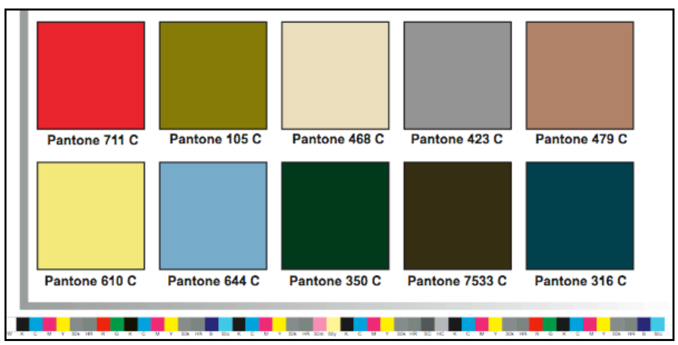


Figure 1. *The supplier was required to print a set of 10 Pantone® colors as shown here. These colors are within the gamut of most 4-color processes. The printed samples were compared colorimetrically to a specific Solid Coated Pantone Formula Guide book.*

Many print jobs today require special colors and in order to produce them accurately on a page, the Pantone® system can be used. The first of two Pantone colors test used in the suite is to determine how a printing device can produce special colors with a good match to the Pantone Formula Guide. This test will also determine how the RIP is able to detect spot color objects to produce these special colors. A digital file containing 10 Pantone colors (Figure 1) was created for each supplier to print. They were also asked to use the *Pantone Formula Guide (Solid Coated),* Fourth Edition, Third Printing for comparison reasons.

The 10 chosen Pantone colors were expected to be in gamut of most 4 color printing processes. The printed samples from each supplier were measured with an X-Rite 530 device using CIE L*a*b*, D50/2˚ and black backing. The ΔE_{ab} was then calculated between the color on the press sheet and in the formula guide.

Pantone® Colors II

Not all Pantone colors can be produced on a press. When a Pantone color made from the process colors is outside the gamut of the printing device, the color will not reproduce accurately. The second Pantone colors test is done to determine the percentage of Pantone colors each digital printing device can produce. The Pantone Digital Library from Adobe Photoshop CS3 was used to determine which colors were in and out of gamut.

For this purpose an ICC output profile was created based on the full gamut IT8.7/4 target printed by the suppliers. The L*a*b* values from the 1137 colors in the Pantone Digital Library in Adobe Photoshop CS3 were manually transcribed for this test. Using Graeme Gill's Argyll color management library and CMM [Argyll, 2008], command line instructions were used to determine the amount of L*a*b* values that are out of gamut. The commands do not have any tolerance so it simply states whether or not a Pantone L*a*b* value was in gamut (i.e. any Delta E over 0 is considered out of gamut and 'clipped'). To match how people perceive difference in color realistically, a tolerance of 2 ΔE_{ab} and 5 ΔE_{ab} was included in analyzing the results.

Resometer

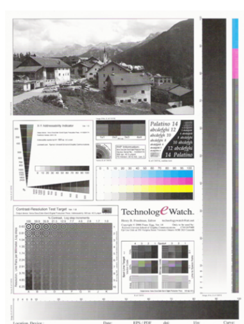


Figure 2. *The Resometer from Technology Watch™ is a digital file (EPS file) that acts as a resolution/resolving power meter. Once this digital file has been output, it will allow the viewer to determine the actual image resolution and contrast of the device.*

The Resometer (Figure 2) from Technology Watch™ is a digital file (EPS file) that acts as a resolution/resolving power meter [Freedman, 2006]. Once this digital file has been output, it will allow the viewer to determine the actual image resolution and contrast of the device. With the Resometer, it is possible to compare with different digital printing devices because standardized reference targets are being used. Performance of digital printing devices can be tested in terms of contrast-resolution, addressability, quality of small type and fine lines, smoothness of gradients, directional tone value changes, and possible different ripping of vector and bitmap images.

The following is a list of targets that are included in the Resometer. By evaluating each target, image quality and resolution capability of the digital printing device could be determined.

- RIP Information Target: indicates the RIP name and information of the output device.
- X-Y Addressability Indicator: used to verify whether the reported addressability of the machine matches its actual addressability.
- Ray Spot Target: determines whether or not too much toner is being printed on the substrate
- Spot Line Target: indicates how positive and negative fine lines are reproduced
- Checkerboard Target: shows how checker patterns are resolved by the RIP
- Contrast-Resolution Test Target: evaluates the resolution capability of the digital printing device.
- Calibrated Gradient: determines the ability of the printing device to produce smooth gradients
- Doubling Grid Target: indicates any directional effects (“slur” or “doubling” in offset printing)
- Small Type Target: determines the ability of the printing device to produce clean and sharp small type
- Pictorial Image: evaluates image quality by evaluating the modulation in the highlights and shadows
- CMYK Step Wedges: used to plot a tone reproduction curve to determine the optical dot gain of a printing device

Simulated Trap

In a four-color process printing environment, each layer of ink printed on a substrate needs to superimpose over a previously printed layer of ink [Breede, 1999]. Not achieving a proper trap value in offset printing affects color balance and results in inconsistent color reproduction. Although toners are different from offset printing inks, it would be interesting to determine the simulated trap that each digital printing device has. All trap values were measured with an X-Rite 939 device using the Preucil equation [Breede, 1999].

Fade Resistance

The early days of inkjet printing were plagued by dyes that exhibited fading and discoloration. Today inkjet prints show very good permanence. It is useful to use similar analysis to evaluate the stability of digital print processes. An accelerated aging test exposes print samples to light and heat to determine their resistance to fading. The lamp emits intense UV radiation, which in a matter of hours approximates the destructive effect of a much longer period of ordinary daylight. Although these tests do not exactly duplicate the effect of prolonged exposure to natural light, they are an effective indicator of the degree of light stability that can be expected of a printed sample.

There are two main types of lamps—ultraviolet carbon arc lamps and xenon arc lamps. We used xenon arc lamps with a daylight filter that mimics the UV radiation found in sunlight, the test therefore simulated outdoor exposure without weathering. The fade tests were done in the Xe1 device that is part of the Q-Sun range of xenon test chambers from Q-Lab (www.q-lab.com).

Blue Wool scale rating	***Time in the test chamber (hours)***	***Equivalent to outdoor summer sunlight***	***Equivalent to outdoor winter sunlight***
#3	5 Hours	4 – 8 days	2 – 4 weeks
#4	10 Hours	2 – 3 weeks	2 – 3 months
#5	20 Hours	3 – 5 weeks	4 – 5 months
#6	40 Hours	6 – 8 weeks	5 – 6 months
#7	80 Hours	3 – 4 months	7 – 9 months
#8	160 Hours	> 18 months	

Table 2. *The prints were subjected to controlled exposures up to 160 hours, which is equivalent to 18 months of summer sunlight, or #8 on the Blue Wool scale. This table gives just an indication of approximate fade resistance times. Fade resistance is lower in intense sunlight locations (e.g., Arizona) and longer in less intense sunlight locations (e.g., Northern Minnesota).*

Samples were exposed in steps, up to a maximum duration of 160 hours. The test mimicked outdoor exposure in a location with high sunshine activity. An established exposure scale is the Blue Wool scale used widely in the testing of products such as pigments, dyes and inks. Blue Wool scale ratings correspond to exposure times as shown in Table 2.

The test was performed as a modified version of ASTM D3424. The international standards ISO 2835 and ISO 12040 were referenced. The DIN 16525 "Testing of Prints and Printing Inks of the Graphic Industry" is relevant.

Rub Resistance

Ink scuffing or rub off during shipping and handling can spoil the effect of quality printed products. The rub resistance of a sample will depend on many variables such as the choice of media, coating, characteristics of the toner particles, etc. Various instruments exist to determine the rub resistance of a printed sample; the Taber test is well established and accepted.

The rub resistance of the submitted samples was tested with two methods. The first method uses the Taber Rub resistance tester to simulate the handling of printed matter in the US postal system. The second method uses the Prüfbau Quartant rub resistance tester. The Prüfbau Quartant rub tester applies a circular motion and a weight to the sample. Both methods simulate the handling and weight of printed matter during transport and handling.

Fold and Crease Resistance

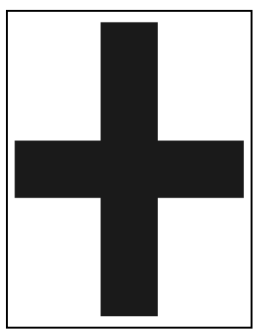


Figure 3. *An image of a 100% K, "black cross," was printed on each supplier system. The sheet was folded in the grain direction and at 90° to the grain direction. The cracked area was digitally analyzed to compute the white paper visible using image processing techniques.*

Output from digital printers can create problems during finishing. Toner sits on top of the paper and does not penetrate the paper like printing ink [Sappi, 2008]. When the sheet is folded the toner can crack. This is especially evident in cases of heavy coverage and/or folding across the grain direction [DiSantis, 2007]. Designers can avoid this problem by not printing across the folds and paying attention to the specification of the paper in terms of grain direction. Traditional folding and creasing machines were not designed for digitally printed media thus there are many new products on the market for digital print scoring and folding.

The test was conducted at the Printing Applications Laboratory, Rochester Institute of Technology according to standardized test method ASTM F 1531. An image of a 100% K, "black cross," Figure 3, was printed on each supplier system. The sheet was folded in the grain direction and at 90˚ to the grain direction. The cracked area was digitally analyzed to compute the white paper visible using image processing techniques.

Results

Gamut Volume

Figure 3 shows the gamut volume of each printing device. As expected, the gamut volumes varied depending on the method/software used to calculate it. This could be explained by how each software interpreted the ICC profiles in order to determine a gamut volume. The gamut volumes calculated by ColorThink were the lowest, while the gamut volumes calculated by Monaco GamutWorks were the highest.

Overall, the digital printing devices contained a higher gamut volume compared to an offset printing press. Konica Minolta bizhub PRO C6500 had the highest gamut volume between the eight digital presses with the two Xeikon devices having the lowest gamut volume. However, high gamut volumes do not necessarily translate to better color quality or color accuracy.

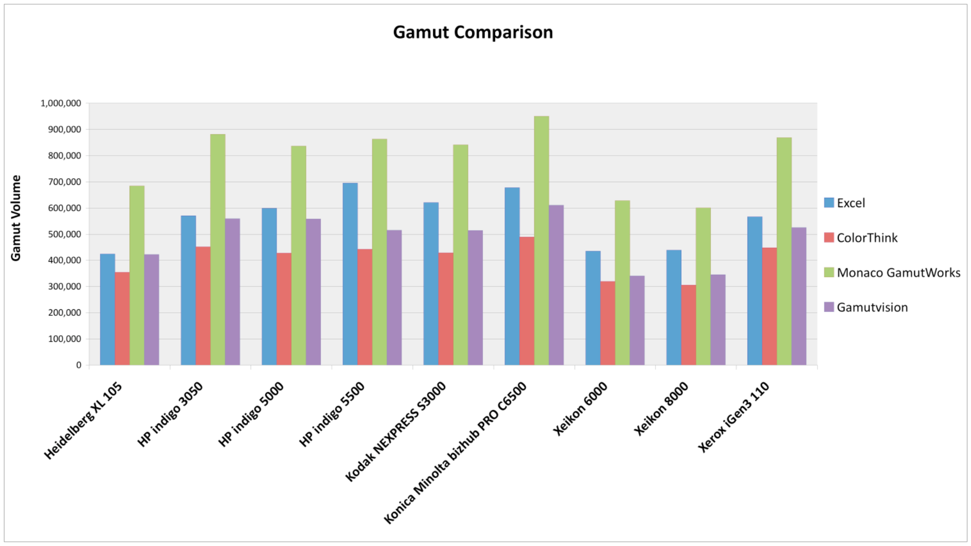


Figure 4. *Gamut volume was determined by four different methods for this test. The first method used an Excel spreadsheet that calculates the volume based on the hexagonal tight sphere packing from crystallography. The second, third and fourth methods involved using the following programs to determine the color gamut with ICC profiles created from the IT8.7/4 targets: ColorThink Pro 3.0.1b20, Monaco GamutWorks 1.12, and Gamutvision 1.37.*

This result indicates that while there are differences in the mathematical basis for the gamut volume calculation but relative to each other it is possible to make valid inter-supplier comparisons.

Pantone Colors I

The ten Pantone patches on each printing device's press sheet were measured along with the Pantone Formula Guide. The ΔE_{ab} was computed between the press sheet and the Formula Guide for all ten patches of each supplier submission. Figure 5 shows the maximum and average Delta E values for these ten patches. It is interesting to note that all the digital printing devices performed better in terms of producing the selected pantone colors compared to the Heidelberg XL 105 with some Delta E values as low as 3. In order for printers to effectively evaluate their digital printing device, selecting common Pantone colors often used for their customers could help determine its Pantone color reproduction ability.

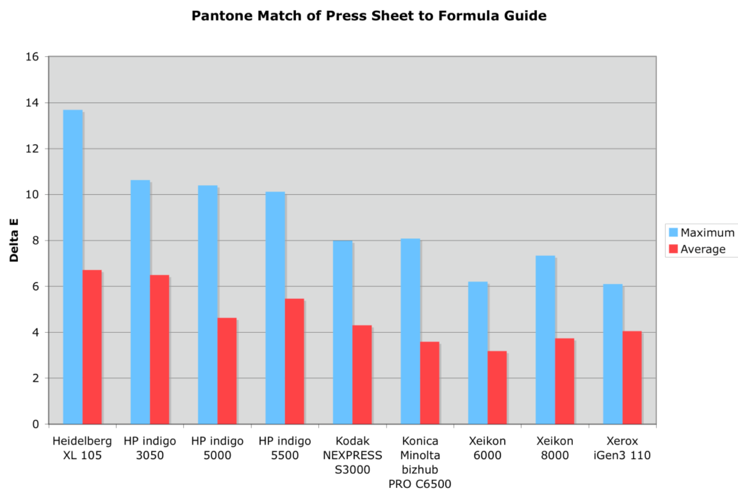


Figure 5. *Suppliers were asked to match 10 in-gamut (GRACoL) Pantone colors. The same Pantone color was measured from a Formula Guide, ΔE between the press sample and the Formula Guide is shown here. In this graph, a lower number is better.*

Pantone Colors II

The percent of reproducible Pantone colors from Adobe Photoshop's Pantone digital library was computed using Graeme Gill's Argyll color management library. It determines the amount of L*a*b* values being clipped (out of gamut) for the printing device. Originally the clipping was calculated with no tolerance or latitude in his calculation, a Pantone L*a*b* value was either in or out. In order to better match the results to what we see in practice, a tolerance of 2 ΔE_{ab} and 5 ΔE_{ab} were used as well. Figure 6 shows the percentage of reproducible Pantone colors for each device. Having a tolerance of 5 ΔE_{ab} produced approximately 20% more Pantone colors compared to having no tolerance at all. From the results, we can see that most digital presses consistently match more Pantone colors than offset, even without the addition of additional inks beyond process colors. Out of all the systems, the Konica-Minolta bizhub PRO C6500 device produced the highest percentage of Pantone colors.

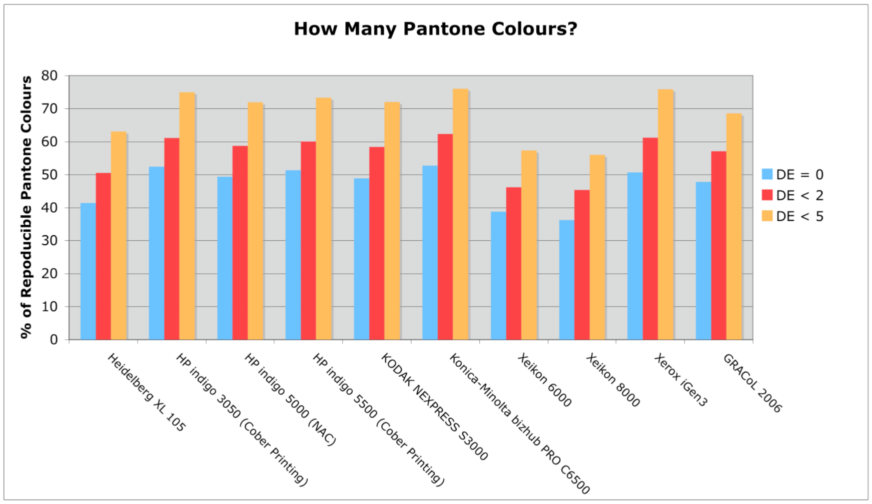


Figure 6. *Argyll CMM was used to identify Pantone colors that are out of gamut of the digital printer using an ICC profile of the device. This unique test uses the Pantone digital library to identify the patches that are out of gamut. In this graph, a higher number is better.*

Resometer

The results from the Resometer are summarized on a table in the Appendix. The following are the detailed descriptions and results for each of the targets on the Resometer test form.

RIP Information Target

The addressability and RIP information is displayed on the Resometer test form when it is printed. It is recommended to print the EPS file of the Resometer in order to produce a test form with complete RIP information. If an EPS file is printed, the RIP name will be displayed but if the EPS file is opened in Acrobat instead of the RIP the word "Distiller" will be displayed. Both the Kodak NEXPRESS S3000 and Konica-Minolta bizhub PRO C6500 had "Distiller" displayed on the output device information, which indicated that a distilled PDF file was printed as opposed to an EPS file. Therefore, complete RIP information was not attainable for both those devices.

X-Y Addressability Indicator

It is possible that some RIPs report a high addressability but in reality, the printer will only print at a lower mechanical addressability. For example, some RIPs may report an addressability of 2400 spi (spi = spots per inch) but may only print at a lower addressability of 600 spi. The effective resolution is often quoted based on interpolation and not the true device physical resolution. The X-Y Addressability Indicator (Figure 7) is used to verify whether the reported addressability matches the actual (mechanical) addressability. Using the horizontal and vertical triangular “fans” on the target, the actual addressability can be determined. Most of the printing devices’ actual addressability matched their reported addressability. However, the Konica Minolta bizhub PRO 6500 device had a reported addressability of 2400 spi but had an actually addressability of 600 spi. The actual addressability for the HP Indigo 3050 and HP Indigo 5500 could not be determined due to an error in printing the target.

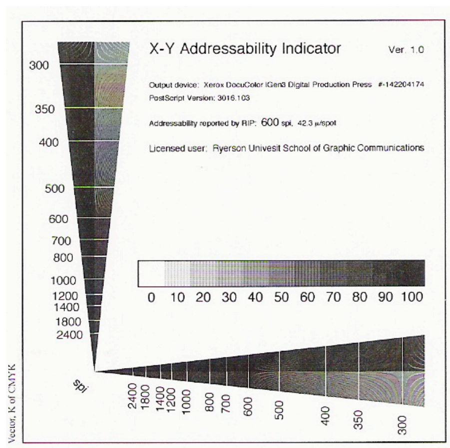


Figure 7. *X-Y Addressability Indicator target.*

Ray Spot Target

The Ray Spot Target (Figure 8) determines whether or not there is too much toner or ink being applied on the printed sheet. It consists of wedge-like rays that are 3 spots wide at the perimeter. White circles mark the width of the rays at 1, 2 and 3 spots wide. The ideal print condition would be to have a black center that is smaller than the innermost white circle. If the black center is larger, it indicates too much toner or ink and the system is unable to resolve the nominal addressability. It is normal that the 45˚ angle rays prints darker compared to the 0˚ and 90˚ due to anti-aliasing. Based on the ray spot target, the following had too much toner on their prints: HP Indigo 3050, HP Indigo 5000, Konica-Minolta bizhub PRO C6500 and the Xerox iGen3 110.

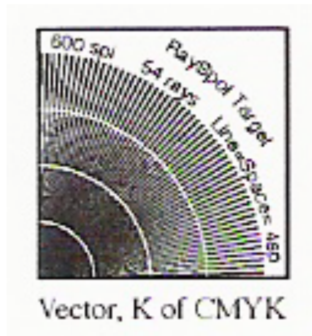


Figure 8. *Ray Spot Target.*

Spot Line Target

The Spot Line Target (Figure 9) shows how positive and negative fine lines are being reproduced on the system. Digital printing devices often put spots that are over inked, which causes positive lines to print too wide and negative lines to print too narrow. The target consists of fine lines that are printed 1, 2, 3, and 4 spots wide with three different spacings: 1:3 (nominal area coverage of 25%), 1:1 (50% area coverage), and 3:1 (75% area coverage) ratios. When evaluating the spot line target, the 1 spot lines should not be darker than the coarser ones. If they are, this indicates that the lines print wider than the nominal width. The following digital printing devices produced acceptable positive and negative lines: Kodak NEXPRESS S3000, Xeikon 6000 and Xeikon 8000.

In addition to indicating the printed quality of fine lines, two different versions of the target are included: one programmed as vectors and the other as a 1-bit image. Although both the targets should look identical, RIPs in the system could render these images differently due to different programming. The following systems had a noticeable difference between the vector and bit image versions of the target: HP Indigo 3050, HP Indigo 5000, Konica-Minolta bizhub PRO 6500, and Xerox iGen3 110.

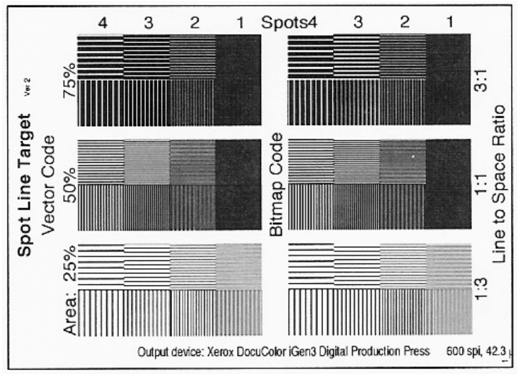


Figure 9. *Spot Line Target.*

Checkerboard Target

The checkerboard target (Figure 10) consists of four checker patterns with different spot sizes: 1x1, 2x2, 3x3, and 4x4. These checkerboards should be resolved down to the 1x1 according to theory but usually that's not the case. This is especially when too much toner or ink is applied, which causes the tone reproduction to become a little darker. In addition, the RIP sometimes substitutes a halftone tint for fine checkers (for example, the 1x1 checkers). This target was evaluated with a weak magnifier (5x) starting from the 4x4 checkers. A progression of finer and finer checkers should be visible from patch to patch. The following devices showed a substitution of halftones on their checkboard targets: HP Indigo 5000, Kodak NEXPRESS S3000, Konica-Minolta bizhub PRO C6500, Xeikon 6000 and Xerox iGen3 110. The Heidelberg XL 105 understandably had halftone substitution since it was an offset press. The Xeikon 6000 was the only digital printing device to produce good checkerboard pattern from patch to patch. Both the checkerboard targets from the HP Indigo 3050 and HP Indigo 5500 were solid black so no results were available for these devices.

Figure 10. *Checkerboard Target.*

Contrast-Resolution Test Target

Resolution is a term often misused as a function of sampling rate or addressability but in reality, it is really a function of contrast. For example, when differences in gray levels cannot be detected, that means resolution does not exist. The contrast-resolution target (Figure 11) allows you to determine the contrast-resolution of a digital printing device. In general, higher resolution is obtained with high contrast detail than with low contrast detail. The contrast-resolution target consists of an array of patches that contains concentric circles in different sizes and contrast. The circles are defined as vector and represent a sampling of image detail. The vertical direction of the target shows logarithmically spaced columns with line frequencies ranging from 6.25 to 0.625 cycles per millimeter. The horizontal direction contain logarithmically spaced rows with contrasts from 100% to 1%. This target is usually used for black since it is the easiest to evaluate and that the resolution capability of black is unlikely to be different from the other colors (cyan, magenta and yellow). [Freedman, 2006]

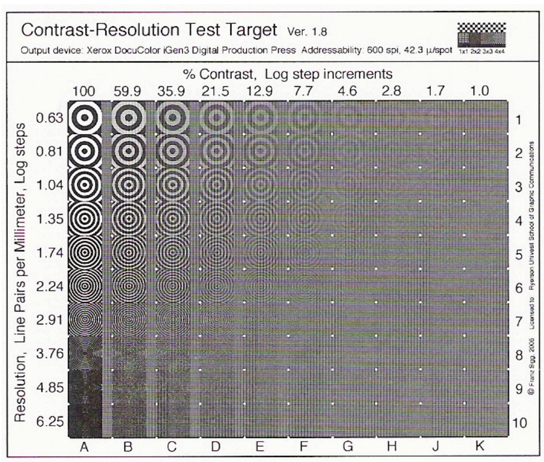
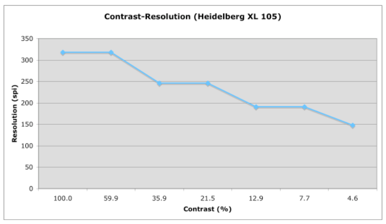
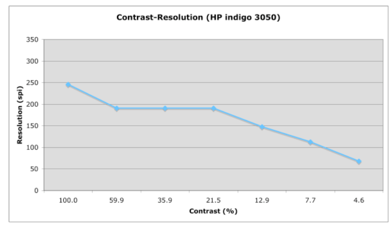
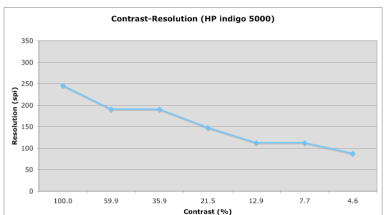


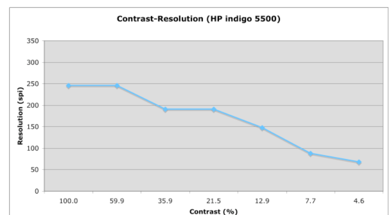
Figure 11. *Contrast-Resolution Test Target.*

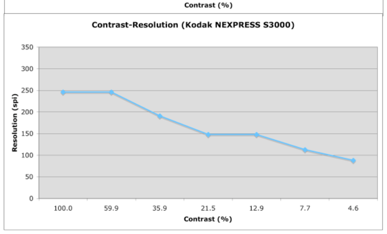
The contrast-resolution target was first observed from the top of Column A (100% contrast) and going down. The key question to ask when analyzing the target is: which is the finest patch that still can be recognized as a circular lines patch and where no lines or spaces are missing or overlapping? Once this patch is found, its resolution was recorded. The same process was done for the other columns until circular lines cannot be seen in the patches. Figure 12 shows the contrast-resolution graphs based on the analysis. In this case, a higher resolution to contrast ratio is favored. Most devices had a resolution of at least 200 spi at 100% contrast, which is an acceptable ratio. The Xeikon 8000 had the highest contrast-resolution ratio (even surpassing the Heidelberg XL 105). It is expected that different observers will choose different patches so results could vary from person to person. For this test, there were two observers involved with the analysis and rules of acceptance were set beforehand.

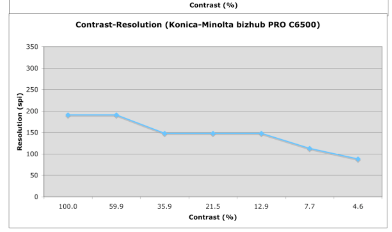


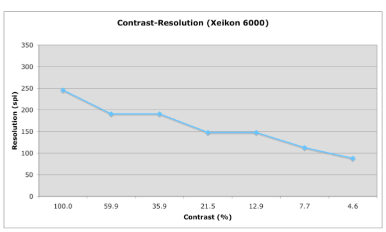












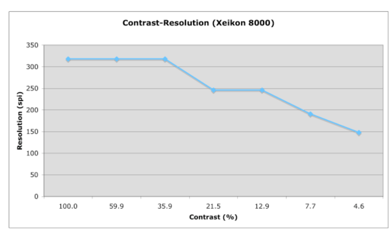


Figure 12. *Contrast-resolution graphs were generated based on the analysis of the contrast-resolution test target. In the graphs, a higher resolution to contrast ratio is viewed as more favorable.*

Calibrated Gradient

Two calibrated gradients are included in the Resometer—a horizontal one and a vertical one (Figure 13). The printed gradients on the Resometer should have smooth changes in the darkness from beginning to end. No steps, streaks or irregularities such as moirés should be visible on the gradient. Irregularities could occur due to screening or unevenness of ink or toner. If irregularities occur on horizontal and vertical gradients, then it is due to screening. If irregularities are only seen on one of the gradients, then it is due to unevenness of toner. Most of the digital printing devices tested demonstrated good reproduction of gradients. Only the HP Indigo 3050, HP Indigo 5500 and Konica-Minolta bizhub PRO C6500 had the gradient being filled in at 92% to 94%.

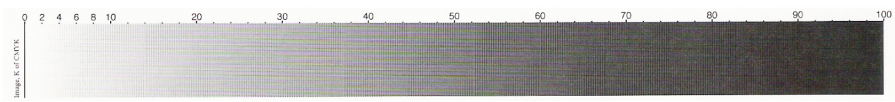


Figure 13. *Vertical calibrated gradient.*

Doubling Grid Target

Located on the right side of the Resometer test form is the doubling grid target (Figure 14), which consists of both vertical and horizontal lines. This target is set at 150 lpi but some printing devices use screening that may not resolve the parallel lines. Directional effects are being tested on this target by comparing these lines. If the vertical and horizontal lines do not have the same darkness, it indicates that there are directional effects (also known as slur or doubling in offset printing). Half of the digital printing devices used did not show any directional effects based on this target. The HP Indigo 3050 and HP Indigo 5500 showed directional effects, which was mostly due to a problem in printing the Resometer test form. The Konica-Minolta bizhub PRO C6500 and Xerox iGen3 110 devices substituted the lines on this target with halftone dots so whether or not directional effects exists could not be determined.

Figure 14. *Doubling grid target (rotated 90º from its original position).*

Small Type Target

The small type target (Figure 15) consists of regular and inverse type ranging from 2 point to 14 point in size. The purpose of this test is to evaluate how clean and sharp the small type is when it is printed. All the digital printing devices were able to at least produce 3 point type (both regular and inverse) that is clean and sharp. Most notably, the Xeikon 8000 device was able to produce clean 2 point text that was comparable with offset lithography (Heidelberg XL 105).

Figure 15. *Small type target.*

Pictorial Image

The pictorial image (Figure 16) on the Resometer is one of the more important elements to look at. Modulation in the highlights of the sky and shadows in the barns should be seen in the pictorial image. Even if all the synthetic targets mentioned previously won't reproduce the way they should, the image could still look acceptable to a "normal" viewer. From looking at the pictorial image from each device, most were able to achieve acceptable image quality. The pictorial image from the HP Indigo 3050, HP Indigo 5500 and Konica-Minolta bizhub PRO C6500 devices were a bit full in the shadows, while the Xeikon 8000 device were a bit light in the shadows.

Figure 16. *Pictorial image.*

CMYK Step Wedges (Optical Dot Gain)

Dot gain is important for the reproduction of images with tonal ranges. The CMYK step wedges (Figure 17) were used to calculate the optical dot gain of each device. Density values were measured for each color and the optical dot gain was calculated for the 25%, 50% and 75% dot areas. It is necessary for printers to control dot sizes because small changes in dot size could affect the tonal values of their reproduction. Dot gain also affects color balance in a four color printing environment so dot gain needs to be around the same for all the colors. Significant higher dot gain values of one color could result in color shifts. Figure 18 shows the dot gain curves for all of the printing devices. As expected, dot gain was the highest in the 50% dot area for all the printing devices so they behave like an offset printing press. The dot gain values between the four process colors for each device were, for the most part, similar and did not show any significant higher or lower differences.

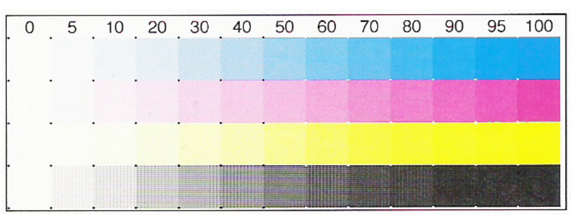
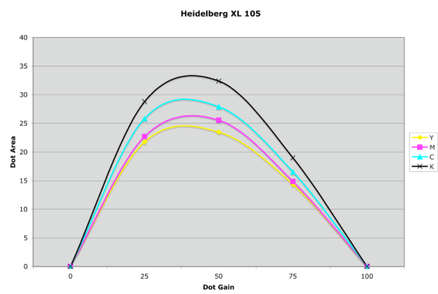
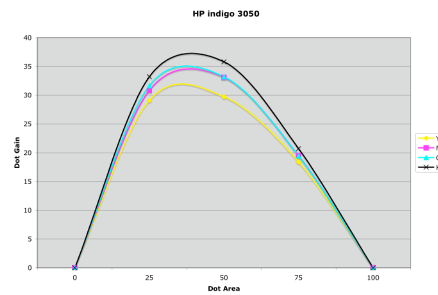
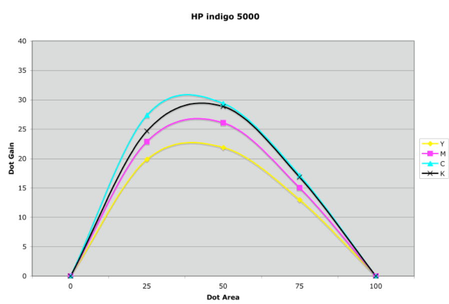
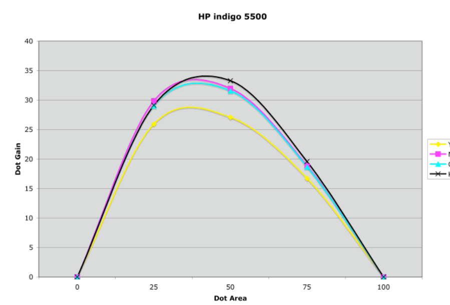


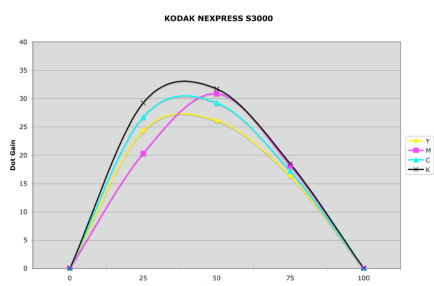
Figure 17. *CMYK step wedges.*

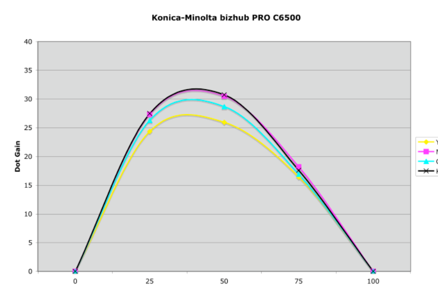

Heidelberg XL 105
Dot Area
Dot Gain
Y
M
C
K

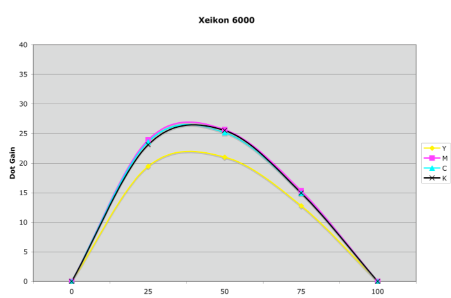

HP indigo 3050
Dot Gain
Dot Area
Y
M
C
K

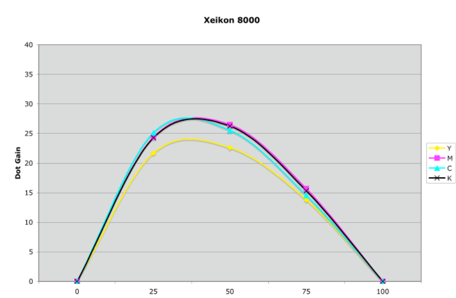

HP indigo 5000
Dot Gain
Dot Area
Y
M
C
K


HP indigo 5500
Dot Gain
Dot Area
Y
M
C
K


KODAK NEXPRESS S3000
Dot Gain
Dot Area
Y
M
C
K


Konica-Minolta bizhub PRO C6500
Dot Gain
Dot Area
Y
M
C
K


Xeikon 6000
Dot Gain
Dot Area
Y
M
C
K


Xeikon 8000
Dot Gain
Dot Area
Y
M
C
K

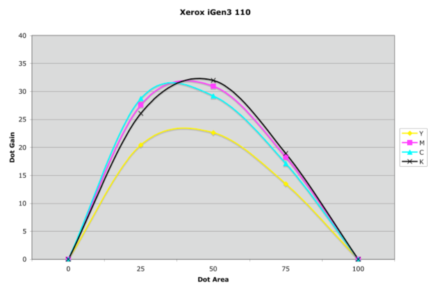


Figure 18. *Dot gain curves for each supplier system base on information from the CMYK step wedges.*

From the dot gain curves it can been seen that all devices try to mimic the dot gain behavior of an offset press, since we are accustomed to that type of look printed matter has. For unknown reasons the HP 3050 and HP 5500 show higher dot gain percentage than conventional offset printing, while the Xeikon 6000 and 8000 print sharper than the XL 105. Quite often the dot gain curves of cyan, magenta and black are very close to each other and much lower dot gain was observed for yellow.

Simulated Ink Trap

Simulated trap on each digital printing device was determined using the X-Rite 939 instrument. Table 3 shows the simulated ink trap values for each printing device. From the results, we can see that trap values on digital printing devices seem are much higher compared to sheetfed-offset standards. These differences in trap values could be explained by the use of toners instead of offset inks for printing. Offset inks usually have different tack values so each successive ink in the sequence will have a decreasing tack value. Toners are transferred onto the paper without the use of different tack values to achieve its simulated trap.

Supplier System	Sequence	R	G	B
HP Indigo 3050	KYMC	100	103	98
HP Indigo 5000	KYMC	101	101	97
HP Indigo 5500	KYMC	103	104	99
Kodak NEXPRESS S3000	KYMC	86	87	79
Konica-Minolta bizhub PRO C6500	YMCK	97	90	87
Xeikon 6000	YCMK	120	115	94
Xeikon 8000	YCMK	111	121	90
Xerox iGen3 110	MYCK	72	103	107
Heidelberg XL 105	KCMY	69	83	71
Approximate trap guidelines (sheetfed offset)		70	80	75

Table 3. *Simulated trap values on each printing device were determined using the X-Rite 939 instrument.*

Fade Resistance

According to the above mentioned standards the exposed samples need to be measured in regards to their L*a*b* values, but a visual inspection also has to take place. In addition to the colorimetric measurements the density of the printed samples was also measured.

Delta E between Exposures

For the offset sample, printed on the Heidelberg XL 105, yellow and magenta faded quickly, as was expected. The digitally printed samples show a much higher resistance to fading than the pigments used in offset printing inks. Some showed fading after 40 and/or 80 hours of exposure in the fadeometer.

Figure 19 shows the large ΔE_{ab} changes for the offset printed samples and smaller and even almost no changes for the digitally printed samples. In this graph a lower height of the bars means better fade resistance.

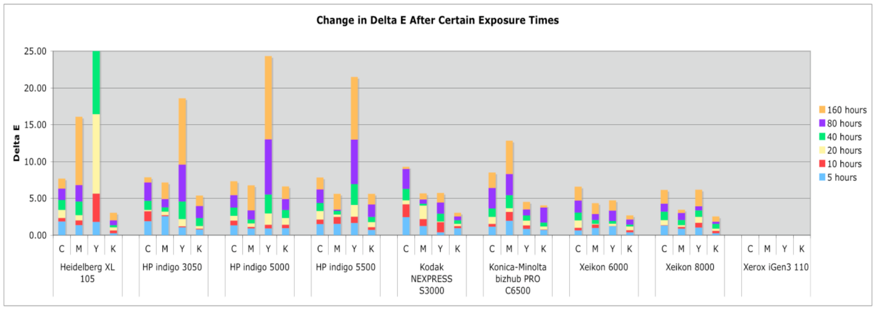
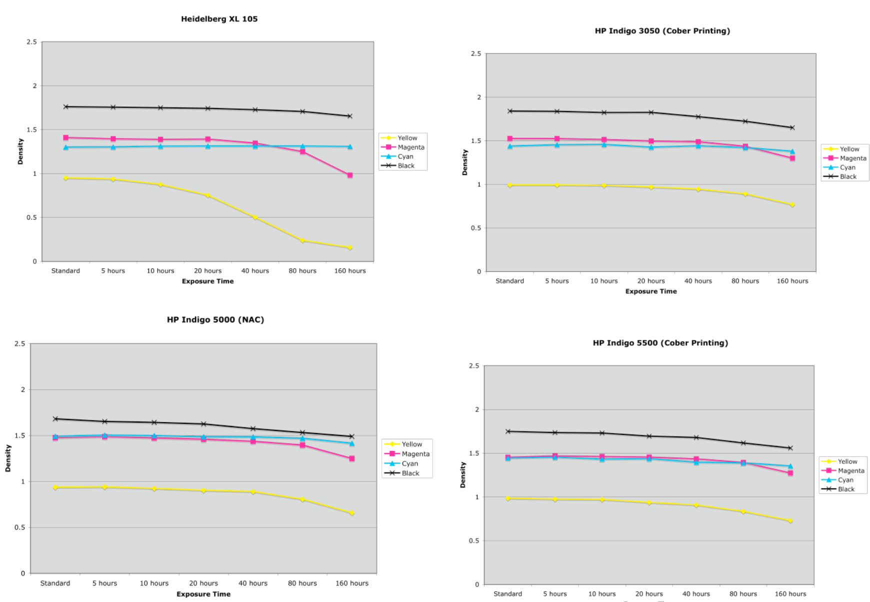


Figure 19. *The bar graphs show the difference in color in DE_{ab} values between the exposure times. The iGen3 110 was not measured. In this graph a smaller bar means less color difference due to fading.*

Density Change with Exposure

The offset printed sample shows a strong decline in printed ink density for yellow and magenta (Figure 20), while cyan and black are almost stable and show no or very little change in density. Most of the digital print devices show very stable density measurements even after 160 hours of exposure. An increase in density can be attributed to the darkening of the printed samples over the duration of the test. Straight lines of density measurements in the graphs represent better fade resistance.



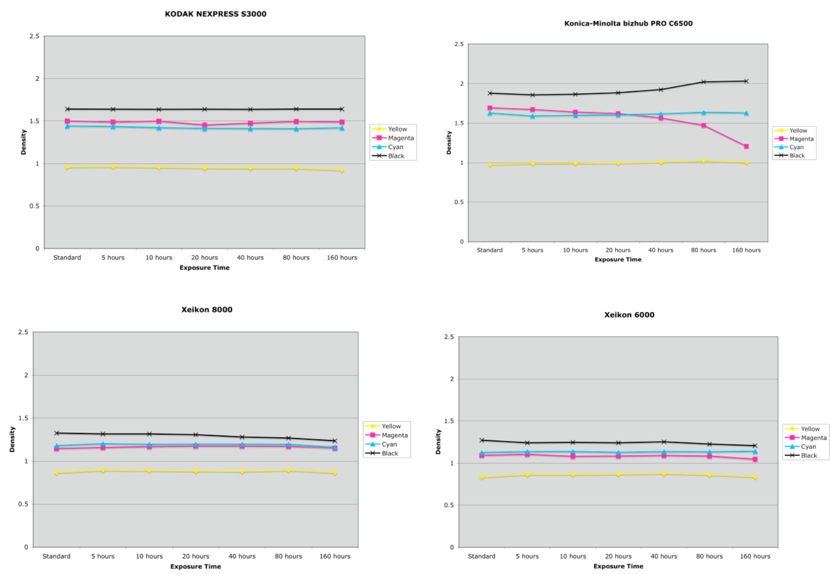


Figure 20. *Density readings of all samples over the duration of the fade test. In this graph a straight line means no change in measured density. The iGen3 110 was not measured.*

Visual Evaluation

A visual evaluation (Figure 21) of the exposed prints was also conducted. The evaluation took place under D50 lighting and represents the results of two observers. Any printed samples that showed no visual sign of fading were labeled "N." Some samples darkened only. In this graph a higher bar means longer exposure hours were needed to result in a visible change in color.

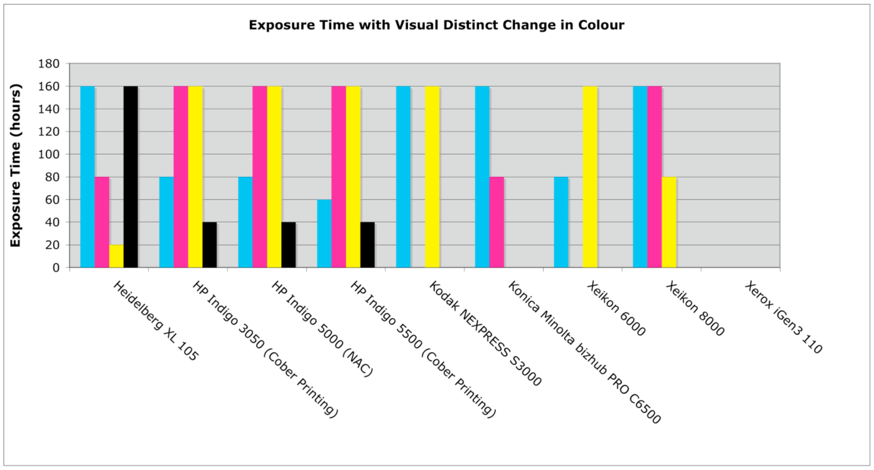


Figure 21. *Visual evaluation of the submitted samples. The iGen3 110 was not measured. In this graph a higher bar means less visible fade of color.*

Interestingly yellow and magenta colors used for digital printing are more stable than cyan and black. This is opposite to the fade behavior of offset inks. Four out of the 8 digital print devices show excellent fade resistance.

Overall it can be said that the colorants used in the digital print devices are more fade resistant than conventional offset colorants.

Rub Resistance

Taber Rub Resistance

The supplier provided printed samples of CMYK blocks. The samples were subjected to a fixed number of 20 cycles. The Taber-Type dry method with 500 gram weight was used. The sample was measured before and after the rub resistance test and the difference plotted for each of the 4 colorants, Figure 22. We note that the HP Indigo demonstrates large loss in density, losing 50–70% of the original density. The loss however, is comparable to the characteristics of offset printing.

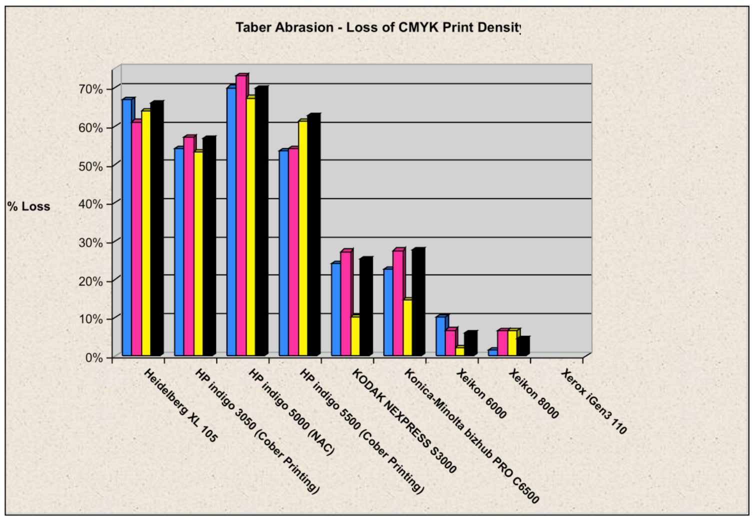


Figure 22. *Data is shown as a percentage change in density between the start image and the finished (rubbed) image. The Xeikon samples were treated using the standard Xeikon print protector (first generation) with the standard Xeikon print protector liquid. This is a treatment whereby a special designed mixture of water, salts, silicon oil and some wax is applied directly after printing, making web based, in-line finishing easier. Xerox did not submit an entry in time for this test to be conducted. In this graph, a lower number is better.*

Prüfbau Quartant Rub Resistance

The Prüfbau Quartant rub resistance tester was the second method used to further test the rub resistance of the printed CMYK samples from each supplier system. To give rub resistance a numerical value, the density of the rubbed off ink/toner was measured. A lower density value is more favorable as it indicates less ink/toner being rubbed off the substrate. The results from this test closely matches the results from the Taber rub resistance test, showing the Heidelberg XL 105 and the HP Indigo 5000 as the least rub resistance. The Xeikon system includes as a normal part of the web-printing process, a treatment whereby a specially designed mixture of water, salts, silicon oil and some wax is applied directly after printing.

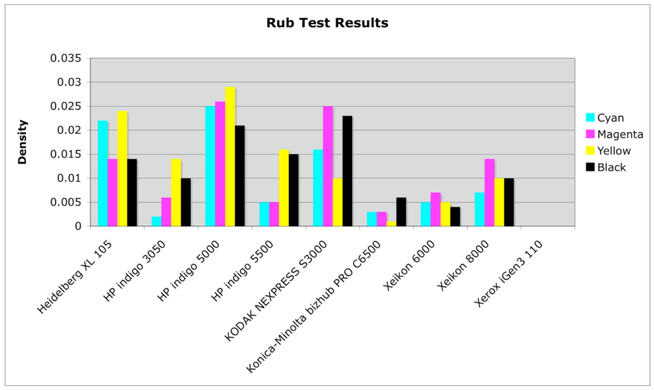


Figure 23. *The density of the ink rubbed off during the test was measured. In this graph, a lower value density value is favored.*

Fold and Crease Resistance

This test was conducted at the Printing Applications Laboratory, Rochester Institute of Technology according to standardized test method ASTM F 1531. An image of a 100% K, "black cross," Figure 3, was printed on each supplier system. The sheet was folded in the grain direction and at 90˚ to the grain direction. The cracked area was digitally analyzed to compute the white paper visible using image processing techniques.

The white area of the paper that is exposed after folding was measured using a microscope and image analysis techniques for edge detection, thresholding and area calculation based on prior pixel to area calibration techniques. The total exposed white paper area in mm^2 was computed for each supplier system, Figure 24. Note that the Kodak NEXPRESS S3000 sample was first printed as 4-color black due to an error by the supplier. Kodak re-submitted their sample as K-only black, this was re-measured by RIT. The graph shows two entries for Kodak, one with a rich (CMYK) black and the second entry as K-only black. All other entries are K-only black. We can use this "oversight" to see the effect of increasing the amount of toner and the difference in cracking between 4-color and 1-color black.

The analysis shows that some devices are better, and others worse, than offset printing. The results serve to warn designers of the need to avoid areas of heavy coverage in the area of a fold.

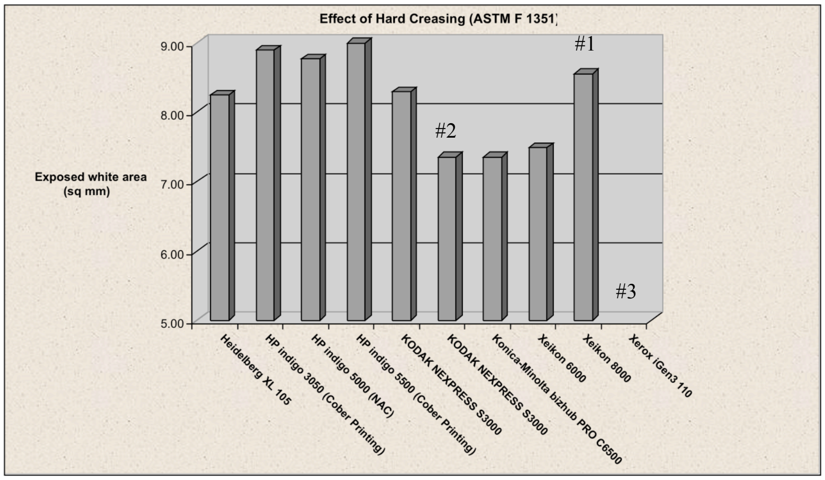


Figure 24. *The white (paper) area visible after folding is shown in this graph. The Kodak entry appears twice, entry #1 is a 4-color black while entry #2 is K only black. It is interesting to use this "re-submission" to see how cracking changes depending on a 4-color black vs. a K-only black. #3 Xerox did not submit an entry in time for this test to be conducted. In this graph, a lower number is better.*

Conclusions

The paper examines introduces a testing suite that can be used to test digital printing devices. The testing suite is comprehensive as it tests many aspects of digital print production such as Pantone colors reproduction, resolution, addressability, physical properties (rub resistance, fade resistance, crack resistance) and de-inking ability. After conducting the entire test on nine systems, it is safe to conclude that the testing suite developed truly shows the abilities of a digital printing device. The testing suite also provided a good snapshot of where digital printing is now and is exciting to know that digital print systems can deliver the quality and performance expected by the markets they serve. Initiating all the tests mentioned in the suite could be costly, so another alternative could be to customize or choose a set of tests that suit the needs of your digital printing device. As the demand for digital printing continue to grow, it will be interesting to see further developments and improvements of this test suite.

Areas of Further Research

The development of this testing suite is just the beginning of what could be an ongoing progression of establishing a standard in evaluating digital print production e.g. ISO 12647-7 and/or FOGRA certification. Digital printing is beginning to be a more popular alternative to traditional offset printing especially in regards to decreasing run lengths. Direct mail and book publishing is an example of markets where digital printing is growing especially with the trend of shorter runs. Additional areas of research should be explored to further our understanding in evaluating digital print production. Future testing could include inkjet devices to see how it compares to offset printing and toner devices. Since digital printing processes differ from offset printing, further research can be done on substrates and what properties are required of them to produce high quality print. With more digital presses approaching press speeds of offset presses, inline or nearline finishing could be an area of interest to study. Lastly, productivity (processing power, uptime and reliability) should be studied in a digital print environment to compare with traditional printing methods. The suggested tests for mentioned has the potential to improve and expand the test suite introduced in this paper.

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Appendix: Resometer Results

	Heidelberg XL 105	HP indigo 3050	HP indigo 5000
Addressability and RIP Name	Heidelberg Normalizer Device Serial No.: 1880096791 2540 spi, 10.0 µ/spot PS Version: 3016.102 Lev. 3	Creo Normalizer JTP Device Serial No.: -1240450945 2400 spi, 10.6 µ/spot PS Version: 3016.102 Lev. 3	LaserWriter-Sim Device Serial No.: 65439 812 spi. 31.3 µ/spot PS Version: 3015.102 Lev. 3
X-Y Addressability Indicator	Reported: 2540 spi Actual: >2400 spi	Reported: 2400 spi Actual: X-Y target was solid black	Reported: 812 spi Actual: ~810 spi
Ray Spot Target	OK	Target was solid black, a lot of toner	OK
Spot Line Target	OK for 75%, lighter in 1 spi for 50% and 25%	Variation between vector and bitmap, filled, solid black	Too much toner for 1 spi
Checkerboard Target	Substituted by halftones	1x1, 2x2, and 4x4 were solid black	No checker pattern for 1x1 patch
Contrast-Resolution Test Target	A,B: 318 spi C,D: 246 spi E,F: 191 spi G: 148 spi H: 88 spi	A: 246 spi B,C,D: 191 spi E: 148 spi F: 113 spi G:68 spi	A: 246 spi B,C: 191 spi D: 148 spi E,F: 113 spi G: 88 spi
Calibrated Gradient	OK	Filled in at 94%	OK
Doubling Grid Target	OK	Directional effects	OK
Small Type Target	Regular Text: 2 pt Inverse Text: 2 pt	Regular Text: 3 pt Inverse Text: 3 pt	Regular Text: 2 pt Inverse Text: 3 pt
Pictorial Image	OK	Full, shadows a bit plugged up	OK

	HP indigo 5500	Kodak NEXPRESS S3000	Konica-Minolta bizhub PRO C6500
Addressability and RIP Name	Creo Normalizer JTP Device Serial No.: -1240450945 2400 spi, 10.6 μ/spot PS Version: 3016.102 Lev. 3	Distiller 600 spi, 42.3 μ/spot PS Version: 3015.102 Lev. 3	Distiller 2400 spi. 10.6 μ/spot PS Version: 3016.102 Lev. 3
X-Y Addressability Indicator	Reported: 2400 spi Actual: X-Y target was solid black	Reported: 600 spi Actual: 600 spi	Reported: 2400 spi Actual: 600 spi
Ray Spot Target	Target was solid black, a lot of toner	OK, a little bit full	Completely filled, too much toner
Spot Line Target	Variation between vector and bitmap, filled, solid black	OK	Variation between vector and bitmap, 4/C Black, Vector code filled in
Checkerboard Target	1x1, 2x2, and 4x4 patches were solid black	No checker pattern for 1x1 patch	All halftones, 4/C, 2x2 patch missing
Contrast-Resolution Test Target	A,B: 246 spi C,D: 191 spi E: 148 spi F: 88 spi G: 68 spi	A,B: 246 spi C: 191 spi D,E: 148 spi F: 113 spi G: 88 spi	A,B: 191 spi C,D,E: 148 spi F: 113 spi G: 88 spi
Calibrated Gradient	Filled in at 94%	OK	Filled in at 92%
Doubling Grid Target	Directional effects	OK	Lines substituted by halftones, 4/C Black
Small Type Target	Regular Text: 3 pt Inverse Text: 3 pt	Regular Text: 3 pt Inverse Text: 3 pt	Regular Text: 3 pt Inverse Text: 3 pt
Pictorial Image	OK, a bit full	OK	A bit full in the shadows

	Xeikon 6000	Xeikon 8000	Xerox iGen3 110
Addressability and RIP Name	iRip Device Serial No.: 10213923 600 spi, 42.3 μ/spot PS Version: 3018.101 Lev. 3	iRip Device Serial No.: 3063533 1200 spi, 21.2 μ/spot PS Version: 3018.101 Lev. 3	Xerox DocuColor iGen3 Digital Production Press Device Serial No.: 1446943877 600 spi, 42.3 μ/spot PS Version: 3017.102 Lev. 3
X-Y Addressability Indicator	Reported: 600 spi Actual: 600 spi	Reported: 1200 spi Actual: 1200 spi	Reported: 600 spi Actual: 600 spi
Ray Spot Target	OK	OK	Slightly too much toner
Spot Line Target	OK	OK	Variation between vector and bitmap, 1 spot lines print wider than nominal width
Checkerboard Target	OK	No checker pattern for 1x1 patch	Checkboard pattern substituted with halftones
Contrast-Resolution Test Target	A: 246 spi B,C: 191 spi D,E: 148 spi F: 113 spi G: 88 spi	A,B,C: 318 spi D,E: 246 spi F: 191 spi G: 148 spi	A: 191 spi B: 246 spi C,D,E: 191 spi F: 148 spi G,H: 113
Calibrated Gradient	OK	OK	OK
Doubling Grid Target	OK	OK	Horizontal lines replaced by halftone dots
Small Type Target	Regular Text: 3 pt Inverse Text: 3 pt	Regular Text: 2 pt Inverse Text: 2 pt	Regular Text: 3 pt Inverse Text: 3 pt
Pictorial Image	OK	OK, a bit light in the shadows	OK