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How Screen's Inkjet Web Printing Exceeds the Stability and Consistency of a Commercial Color Offset

Introduction

Opening High End Color Production Quality and Run Lengths to Inkjet Printing for the First Time

Printing has a unique history of process development as compared to nearly all other technologies; as a major technology it went for centuries unchanged. Gutenberg's 1450 relief image printing process lasted without change for nearly 500 years until offset lithography became the dominant printing process in the 1960's and 70's. Offset continues to be the dominant process today with close to 90% of all printing volume.

Emergence of Substitutes for Offset Printing

No question that within just the past decade new significant technologies and systems have emerged challenging offset lithography at an increasingly fast pace now. A substitute will only survive if it can meet or exceed the benefits of what it is substituting for - in this case, inkjet for offset process.

The increase in the emergence of new printing processes is brought on primarily by the digital age and the ability to develop revolutionary new writing systems and electronic image and process controls. To date, however, the application of the new digital printing processes, primarily made up of toner and inkjet printing, resides with low volume short run printing production.

When applied to longer volume press runs, digital processes have resulted in lower image quality, higher cost, and limited substrate options.

A few manufacturers require an additional process of precoating paper so that their inkjet inks will adhere to conventional papers. This requires adding additional water to paper (paper does not like water), additional jetting heads, pumps, feed lines, component space, monitoring and controls, fluid reservoir and maintenance resulting in increased process complexity, cost, and paper use. Aside from these limitations, the processes themselves have had great difficulty with system stability and consistency of reproduction at run length. In addition, the rub off strengths have been weak. These limitations have kept digital printing from challenging color offset lithography for typical commercial color production length runs.

As the reader will find here, testing shows and verifies that SCREEN Graphics Solutions Co. has now solved these great issues in the engineering of their 520HD SC inkjet web press.

Experimentation Discovers a new Printing Substitute for Offset Run Lengths

In the fall of 2018, Image Test Labs conducted an experiment in conjunction with *Technology Watch Newsletter* and SCREEN to have a process color inkjet web press match a modern sheet fed offset press manufactured in this case by Heidelberg of Germany. This experimentation successfully resulted in the production of a Special Issue of *Technology Watch* Spring 2019 entitled *Matching Offset with Inkjet Web - Making Some History.*

The technical section of this paper will address this experiment as well as prove that a SCREEN 520HD SC inkjet web press can economically produce the image quality of a commercial sheetfed color offset printer at a production length print run. In fact, as you will see, the SCREEN inkjet web press actually exceeded the stability and consistency of the Heidelberg offset press, breaking through the critical limitations that have kept inkjet from true offset production run length work.

Significant Benefits of the SCREEN 520HD SC Press Derived from Stability and Consistency

1. Ability to economically produce a critical color image level over a long run length.
2. Ability to accurately predict the materials and processes used for the printed work.
3. Reduced paper waste on top of a 15-20% lower paper cost than a sheet fed offset press.
4. Faster get to color on press at makeready.
5. More accurate and fine-tuned price estimating to win more work.
6. More accurate scheduling.
7. Reduced environmental impact of press run.
8. The increased stability and consistency has produced a uniformity level required for the packaging printing market.
9. A reduced processing load requirement for inline error detection and correction systems.

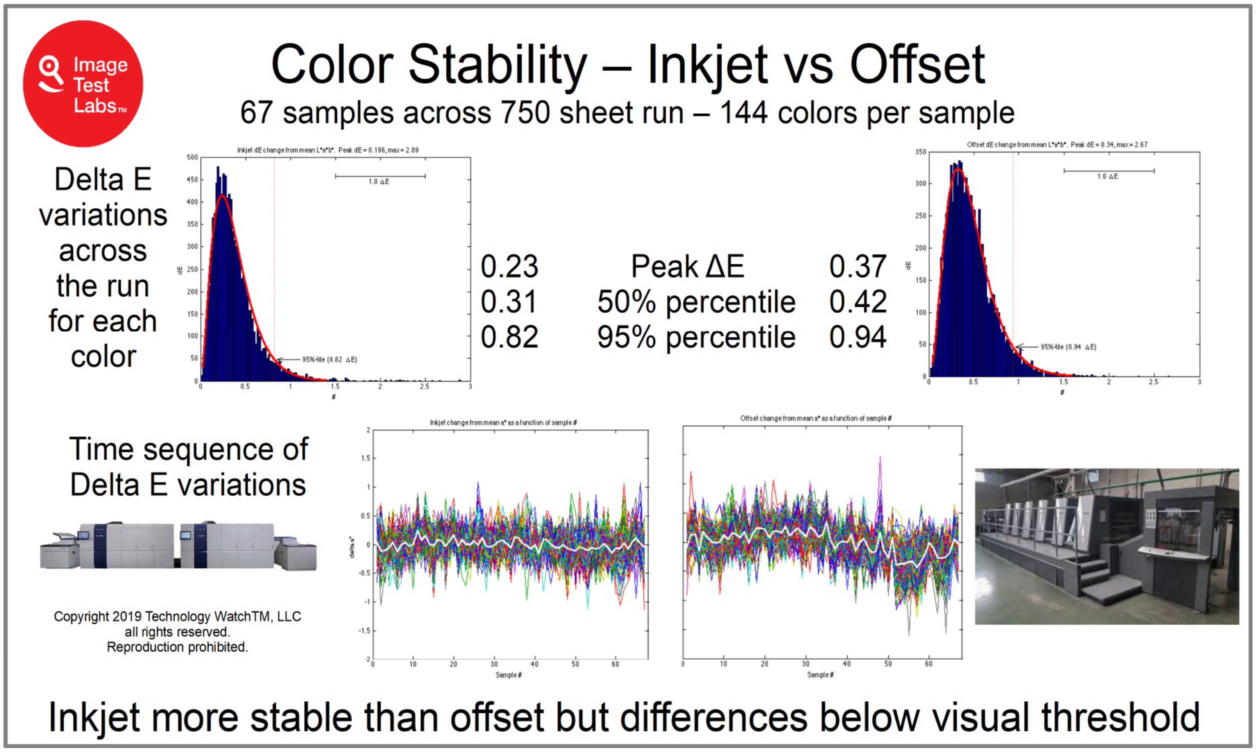
Based on the above discussions, the SCREEN 520HD SC press is the first inkjet press to have successfully made the historic breakthrough into offset sheetfed commercial color production volume work on a modern printing plant floor.

Technical Discussion

The next three sections each cover the results and technical details of the consistency and stability of the color in the Match prints made on the commercial offset and inkjet presses. The sections cover the same basic material but in increasingly greater technical depth.

ITL 520HD SC NIR vs Heidelberg XL 105 Offset Press for Match Run - Stability and Consistency Chart Description

For the Match project, the goal was a visual match between offset and inkjet prints but it was understood that a more comprehensive understanding of what our presses in Rochester and Chicago were performing during the months it took to create Match and then produce the thousands of samples, all of which matched. Accordingly, small 144 patch targets were put on each sheet with the three Match pages and each time we printed a match page, we gathered a color signature – for the critical colors of the Match and for a wide set of colors. The results gave us a lot of confidence. When the two production runs were completed in Chicago and Rochester and the newsletters were cut out, the targets were harvested for a postmortem.



The upper charts have 10,000 data points showing how much each individual color patch varies from the mean of its color. The inkjet has a tighter distribution, though both presses have only a few percent of the points outside one delta E. They both look very good, but averaging all the data together could mask some interesting details.

The lower charts follow the time sequence for the 144 patches – 144 lines tracking the a* variation for each color patch from its mean value. The offset chart in the lower right definitely has something going on. The average of all colors (the white line down the middle) jumps around about a quarter of a CIE unit slowly and then has a big drop (0.3 CIE) about three quarters of the way through the run and then slowly recovers. The inkjet average is somewhat quieter and has less structure. This chart prompted a deeper look into the systems performance of both presses and led to the generation of a comprehensive White Paper.

Executive Summary

The Match Challenge[1] was devised to evaluate the capability of a SCREEN 520HD SC inkjet press with a Near Infrared Dryer to consistently match the printing capability of a high-end, well-maintained offset press in an image quality comparison over a long run with identical content printed side-by-side on the same substrate. The test form created for the Match Challenge contained challenging text, graphic and image content along with a control chart with 144 color patches for objective measurement of press imaging characteristics throughout the inkjet press and offset press runs.

First the top half of the 18x38 inch panel was printed on the 520HD. Then the 38 inch panels were sheeted from the roll and the lower half printed on the Heidelberg XL105 offset press. The vertical CMYK bars were printed by the inkjet as part of the nozzle maintenance action recommended by Screen.

Half the sheets (753) were trimmed to 11x17 Match pages (2259 pages) for distribution and the 753 color patch sets saved. To assess the consistency of printed colors, 67 patch pairs were selected (selection details later) measured with an X-Rite iSis 2 XL scanning spectrophotometer

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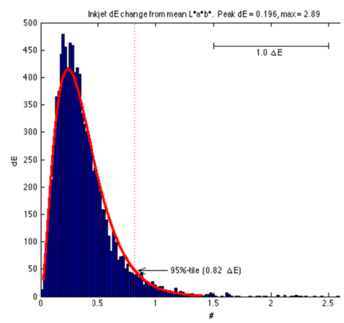
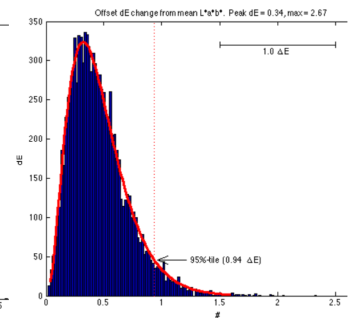
1 The Match Challenge is reported in the May 30, 2019, issue of Printing Impressions https://www.piworld.com/article/image-test-labs-makes-printing-industry-history-matching-image-reproduction-offset-inkjet-web-printing/ and also in a Printing Impressions video https://www.piworld.com/xchange/offset-printing/inkjet-web-output-matches-commercial-sheetfed-offset-quality-during-production-test-run/

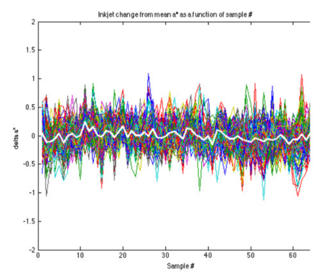
and analyzed. This data became the basis of a inkjet and offset color consistency analysis which is reported here.[2]

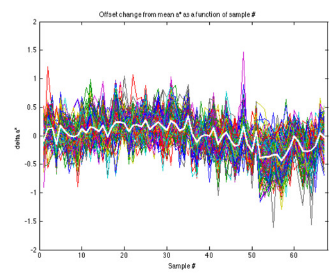
First, histograms for the color variations (ΔE from the means of each patch) were created for all of the 144 patches for the inkjet and offset targets across all 67 pages – almost 10,000 data points for each of inkjet and offset printing processes. The charts are at the right – inkjet and then offset. One ΔE of color difference is barely distinguishable in side-by-side viewing under ideal viewing conditions and 2 ΔE would certainly suffice for any image-to-image comparison. Almost all the inkjet samples and 95% of the offset patches are better than 1 ΔE. By most metrics, the inkjet is 30-40% "tighter" than the offset. While this data does not indicate any issues with consistency in either the inkjet and offset printing, the color consistency as determined by this pooling of 10,000 data points shows that the color consistency of the inkjet press is statistically, if not visually, better than the offset press. The data warranted further study.





The second study looked at variation of the CIE colorimetric components (L*, a*, b*) for each of the 144 patches across the run from their mean values. The chart of the inkjet data on the left shows that the inkjet trends of patch measurements stay within +/- 0.5 CIE units. The average of the variation in each sampled page is shown as a white line running down the middle. The offset trends on the right have slightly greater "noise" and some long term and short term correlated excursions. The next section of this report will discuss these charts in more detail. Again, these variations are below the visual threshold but certainly indicate that the color rendering of the inkjet prints are more stable and consistent than the offset prints.





Subsequent sections of this report expand on the analyses described above and explain how the observed color variations reflect on the performances of the process controls of the inkjet and offset presses used.

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2 Printing Impressions produced a video about this consistency test https://www.piworld.com/xchange/digital-printing/henry-freedman-new-photographic-printing-technology-color-stability-inkjet-offset/ The relevant section starts at 6:30 and runs for 5 minutes.

The Match Challenge and the Evaluation of Consistency

The Match Challenge was devised for evaluation of the capability of a Screen 520HD inkjet press to consistently match the printing capability of a high-end, well-maintained offset press in an image quality comparison over a long run with identical content printed side-by-side on the same substrate.

To avoid measurement overload, a print sampling plan that is statistically representative of a complete print run was required to analyze the process consistency between the long print runs of the SCREEN 520HD inkjet press and the Heidelberg XL105 offset press. We selected control chart samples, according to the sampling procedure recommendations of MIL-STD 105E and ANSI/ASQ Z1.4 (2008), from 67 sheets, randomly dispersed through the set of 753 18" x 38" sheets of the Match Challenge print run selected for distribution and analysis.

Control chart patch measurement with an X-Rite iSis 2 XL scanning spectrophotometer showed a short-term repeatability of within 0.1 ΔE and a combined print noise plus instrument noise repeatability measured to be less than 0.25 ΔE.

Analysis

In our analysis of the data from some 19,296 measurements of the inkjet press and offset press match runs, we evaluated color consistency capability from four different perspectives:

1. We looked at the entire mass of data and evaluated how the magnitudes of individual patch color variability were distributed. Color consistency advantages can be found in comparison of the two distribution shapes.
Conclusion: Inkjet press color variability was lower, and color consistency was higher, over the entire 16,000-foot press run than that observed in the matching offset run (compare the histograms of Figure 1 and the summary in Table 1, below).

2. We looked at how color variability changed within the runs to evaluate press stability. Stability is required to achieve consistency in the reproduction of color.
Conclusion: Measures of overall statistics as well as trends throughout a run show a clear inkjet press advantage in achieving consistent color reproduction (compare the histograms of Figure 1 and the trend charts of Figures 2 and 3, below).

3. Process capability indices, such as C_{pk}, provide a clear indication of the ability of a color reproduction system to deliver stable and consistent output.
Conclusion: All of the component process capability indices for controlling color variability in the inkjet press run are exemplary and better than the corresponding process capability indices for the offset press run (comparison summarized in Table 2, below).

4. From our analysis of press stability, drift was identified as the major source of instability. Drift in the two press runs, one inkjet and the other offset, was examined with a very sensitive tool called EWMA.

Conclusion: The capabilities for controlling the mean variability and maintaining the consistency of the color reproduction process in the inkjet press run are clearly superior to the capabilities shown in the offset press run (see Figures 4 and 5, below).

Color consistency within a press run is explicitly linked with the measured color variability within that run – lower color variability results in higher consistency and the many advantages in production printing that higher consistency brings. In the two runs of the Match Challenge we had a rare opportunity to directly compare a long inkjet press run with a matching long offset press run printed side-by-side on the same substrate. The objective basis for our analysis is provided by measurements of the two sets of 144 patch targets printed side-by-side on our selected print samples, one set printed by the inkjet press, the other set printed by the offset press. We measured color reproduction variability within a run as the color difference of individual patch measurements from the average of those patch measurements over the entire run.

Color variability

- *Both presses behave very well with only a few percent of color variability measures*

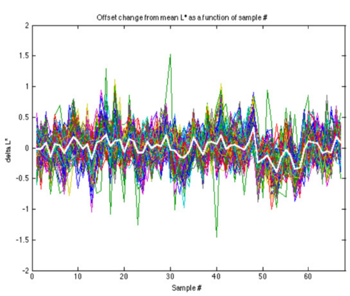

Figure 2a: Offset L* variability vs. sample

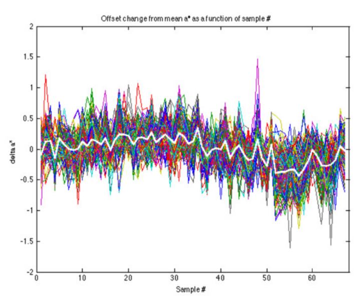

Figure 2b: Offset a* variability vs. sample

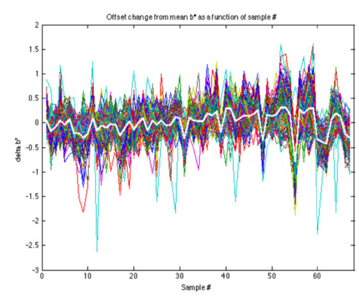

Figure 2c: Offset b* variability vs. sample

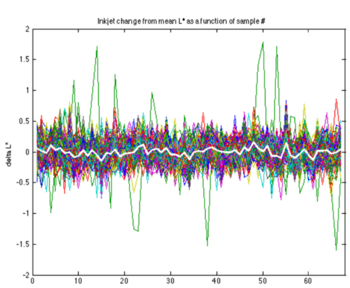

Figure 3a: Inkjet L* variability vs. sample

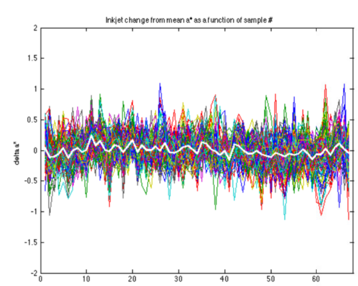

Figure 3b: Inkjet a* variability vs. sample

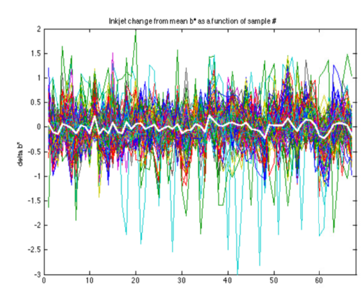

Figure 3c: Inkjet b* variability vs. sample

exceeding one ΔE, a realistic value for a just noticeable color difference between two adjacent color patches.

- *Inkjet press color variability was lower, and color consistency was higher, over the entire 16,000-foot press run than that observed in the matching offset run – with the two matching runs printed side-by-side on the same substrate.*

Measurement of the pairs of 144 patch control charts on each of the 67 sample sheets randomly dispersed through the inkjet press and offset press runs were made with 1976 CIE L*a*b* colorimetry where a 1.0 ΔE color difference from a measured reference patch value is a reasonable estimate of a just-noticeable color difference in critical comparison of adjacent patches. The ΔE measure has components ΔL* (a Lightness or neutral change), Δa* (a chroma change along the red – green axis) and Δb* (a chroma change along the yellow – blue axis). The distribution of all the measurements of individual patch ΔE color variability over the entire inkjet press run is shown in the histogram (number observed as a function of ΔE color difference) shown in Figure 1a. The histogram of figure 1b shows the distribution of the individual patch color variability measures for the entire offset press run.

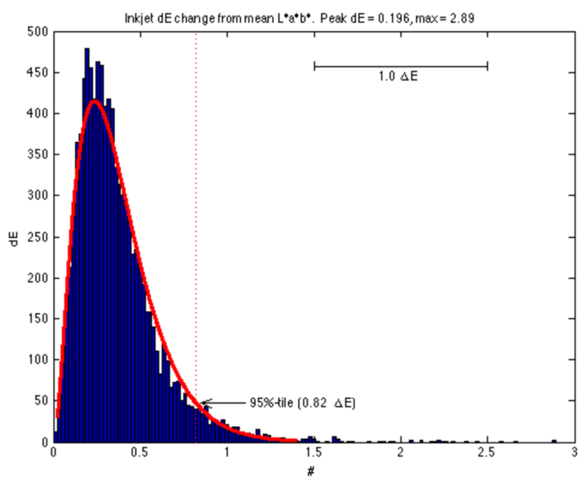

Figure 1a. (inkjet)

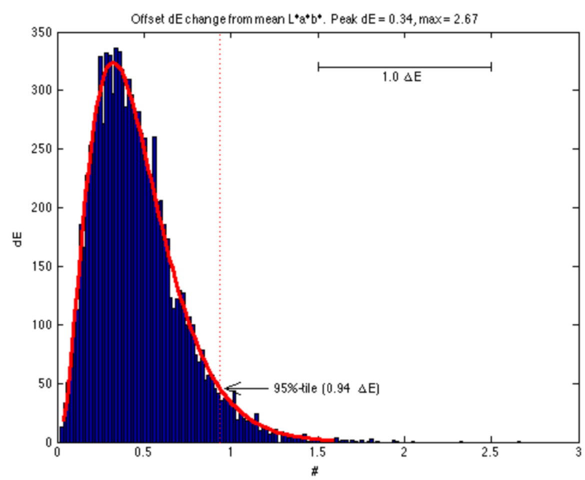

Figure 1b (offset).

Comparison of these two histograms shows that the distribution of the measured inkjet press color variability is narrower than the distribution of the measured offset press color variability. Table 1a summarizes the peak position, mean and width characteristics of overall color reproduction variability in the inkjet and offset runs.

	Inkjet	Offset
ΔE distribution peak:	0.20	0.34
ΔE distribution mean:	0.37	0.46
ΔE range for 95% of data:	0.82	0.94

Table 1a, distribution statistics

	Inkjet	Offset
ΔL* run trend standard deviation:	0.06	0.14
Δa* run trend standard deviation:	0.08	0.19
Δb* run trend standard deviation:	0.10	0.22

Table 1b, average trend statistics

Trends in color variability

- *All of the measures of color variability summarized in Tables 1a and 1b, overall statistics as well as trends throughout a run, show a clear inkjet press advantage in achieving consistent color reproduction.*

Figures 2 and 3 show the measured data trends in the component color variability measurements, ΔL*, Δa* and Δb*, over the 67 sets of sample patch measurements. In the Offset run data trends shown in Figure 2 some drift is evident in the envelopes of the individual patch measurement differences from their average values over the run (individual color lines) and in the averages over all color patches on a page (white average lines through the envelope of individual patch measurements), particularly in the Offset a* color variability trend of Figure 2b.

The Inkjet run data trends shown in Figure 3 show little evidence of drift in either the envelopes of the individual measurements or in the averages over all color patches on a page

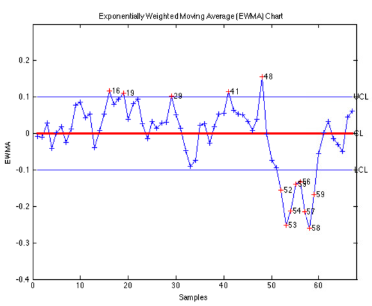

Figure 4a: Offset ΔL* EWMA chart

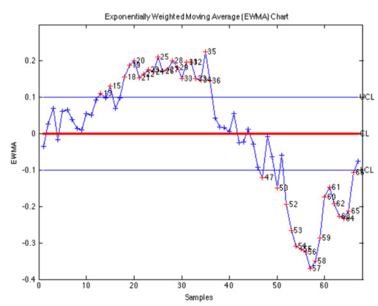

Figure 4b: Offset Δa* EWMA chart

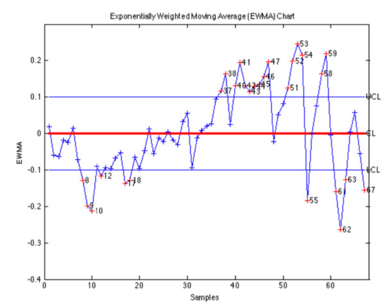

Figure 4c: Offset Δb* EWMA chart

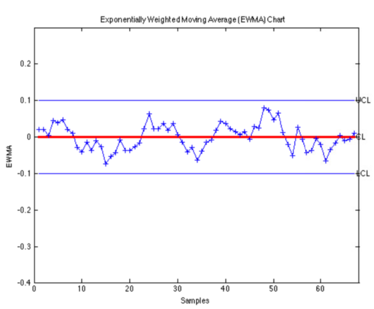

Figure 5a: Inkjet ΔL* EWMA chart

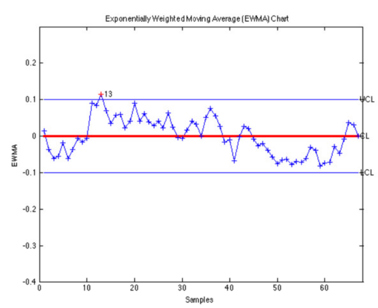

Figure 5b: Inkjet Δa* EWMA chart

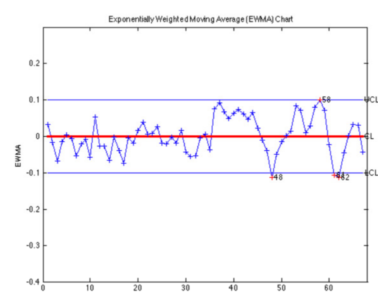

Figure 5c: Inkjet Δb * EWMA chart

(page-averaged data shown as white lines). The inkjet press page-averaged data is also less noisy than the offset run. A good statistical measure of the variability from page-to-page of the page-averaged data is provided by its standard deviation, tabulated in Table 1b.

Outliers, seen as large deviations from zero, consistently come from particular color patches (distinct color lines in Figures 2 and 3) and are particularly evident in the Inkjet b* trends of Figure 3c (which contribute to the long tail of the ΔE distribution shown in Figure 1a). This characteristic is the only apparent weakness of the inkjet press.

These measurements summarize the visual difference between equivalent sets of nearly ten thousand measurements each printed on the same sixty-seven sheets of paper by both the inkjet press and the offset press.

Process capability

- *All of the component process capability indices for controlling color variability in the inkjet press run are exemplary and better than the corresponding process capability indices for the offset press run.*

A useful descriptor of process capability is provided by the C_{pk} measure: the ratio of the closest approach of an average process value to an upper or lower control limit (numerator) with the variability of the process as measured by 3 times the standard deviation of the process (denominator). A useful process is generally characterized by a C_{pk} of one or greater. Process capability indices scale linearly with the magnitude of the control limits imposed on the process. As mentioned earlier, a 1.0 CIELab measurement difference represents a good estimate of a just-noticeable color difference to an observer with normal color vision when critically comparing adjacent patches. If color variability were held within one ΔE then under worst-case conditions (uniform, large patches with significant color differences immediately adjacent to each other) most observers would not detect any color difference.

Held to a stringent one ΔE limit, all of the component ΔL*, Δa* and Δb* process capability indices for controlling color variability in the inkjet press run are better than the corresponding process capability indices for the offset press run and all the component process capability indices for controlling color variability in the inkjet press run are greater than one. Table 2 summarizes these results.

	Inkjet process:	Offset process:
Cpk for ΔL* = 1	**1.72**	1.30
Cpk for Δa* = 1	**1.5**	1.12
Cpk for Δb* = 1	**1.01**	0.95

Table 2.

Drift in color variability

- *The capabilities for controlling the mean variability and maintaining the consistency of the color reproduction process in the inkjet press run are clearly superior to the capabilities shown in the offset press run.*

Xbar, R, S and EWMA charts are tools commonly utilized to analyze process capability. The Xbar and EWMA charts examine the stability or drift in the mean value of a process variable. The R and S charts examine the stability or drift in the range and variability (standard deviation), respectively, of a process variable. The EWMA (Exponentially Weighted Moving Average) chart provides a sensitive measure of changes in the mean of a process variable.

EWMA analysis employs a weighted cumulative sum of measurement data. If measurements are randomly distributed around a zero mean value, the plot will jump around the zero line with no drift towards a limit.

The inkjet ΔL* plot of Figure 5a illustrates this desired behavior. If there is gradual drift, this drift will accumulate quickly to produce a trend towards a limit value. The offset Δa* plot of Figure 4b illustrates this undesirable behavior. The offset press drift behavior shown earlier in Figures 2a, 2b and 2c shows clearly in the EWMA analysis, particularly in the offset Δa* EWMA plot of Figure 4b, as does the mean shift in color variability that can be seen in Figures 2a and 2b near sample number 50. An Xbar control chart analysis shows similar mean variability behavior results but in a less clear manner than with the EWMA charts.

Conclusions

Color prints from a well-maintained offset press with an experienced operator are regarded as quality reference in production color printing. This study, comparing the color reproduction consistency of a long print run produced by a very good sheet-fed offset press and operator with the color reproduction consistency of a roll-fed inkjet press, has shown that the inkjet press consistency is as good as or better than the consistency of the reference offset press. This leads to several observations:

1. A more consistent process provides the capability for relaxed inspection, saving both time and resources.
2. A more consistent process can provide efficiencies in both scheduling and in future re-runs.
3. Better consistency can provide a faster setup to color aims, again saving both time and resources.
4. Better consistency can provide opportunity to enter new markets, particularly the packaging market.