Color Uniformity of Electrophotographic Presses

Dr. Anthony Stanton*, Dr. Mark Bohan**, and Lindsay Ferrari**

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Abstract

This study extends the color uniformity study published by Stanton, Bohan, and Ferrari in the *2013 TAGA Proceedings.* (Stanton, et al, 2013)

The 2014 study examined the color uniformity of seven electrophotographic press systems compared to the color uniformity of an Epson inkjet proofing device. The electrophotographic presses were coded for this study as PA through PG. One of the electrophotographic presses, PC, was tested under two different conditions: before and after cleaning and maintenance. These two conditions are coded as PCb and PCa, respectively.

Eleven test pages were measured for each press. Each of the 11x17-in. pages was filled with a solid color. The colors were chosen based on their performance in the 2013 study of color uniformity. Large solid-color areas allowed for comprehensive measurements of color uniformity, and mimicked a common requirement in advertising printing for large areas of solid color.

Although subjective evaluations were not used in this study, the large solid prints contained streaks and other defects that were not apparent in the 2013 study, where small color spots repeated across the page were used for calculation of color uniformity. The authors feel that objectively characterizing these defects is a good topic for further study.

The color uniformity index used for this study was based on ΔE2000 color difference values calculated from all of the paired comparisons from 96 uniformly spaced CIELAB measurements that were made from each sheet, or 4,560 comparison pairs per sheet. The ΔE2000 values represent calculated differences between two color samples on a scale correlated to human perception. The relationship is designed such that one ΔE2000 unit equates to a just noticeable difference for a standard

* Carnegie Mellon University
**Printing Industries of America

human observer under a defined light source.

The mean of the 4,560 ΔE2000 values for a given sheet yielded the color uniformity score. Lower mean values indicate more uniformity of color. For each press in the study, the color uniformity scores for the 11 colors included in the study were averaged to determine that press's overall color uniformity score. The uniformity scores for each of the presses were based on 50,160 calculated ΔE2000 values. The large sample sizes resulted in tight confidence intervals around the estimation of mean color uniformity scores.

The hypothesis of the study was that the color uniformity scores for all of the electrophotographic presses would be equal and that the uniformity of the individual colors would also be equal. Based on the 2013 study, it was assumed that the inkjet proofing device would have better color uniformity than the electrophotographic presses.

ANOVA testing revealed that the color uniformities of the seven electrophotographic presses were significantly different from one another with the exception of presses PA and PE, which were found to be equal. These two presses also had the best color uniformity of the electrophotographic presses. The range of mean ΔE2000 values for the electrophotographic presses was 0.96. Thus, the average color difference for the least uniform of the presses was about one just noticeable difference higher than the average color difference for the most uniform press. None of the electrophotographic presses exhibited extremely poor color uniformity compared to the group. Interestingly, the press that was tested before and after cleaning and maintenance (PC) had better color uniformity before cleaning than after.

As expected, the inkjet proofing device had significantly better color uniformity than any of the electrophotographic presses. The uniformities for individual colors across all electrophotographic presses were also found to be different from each other, with the exception of two colors: G6 and G9, the two colors in the study from the red domain. The ranking of the colors in order from greatest to least color uniformity is shown in Table 5. Overall, the pastel colors had the best color uniformity, and darker, near-neutral colors were among the worst.

When the influences of individual colors were tested for individual presses, the results were complex. There were different equal and unequal colors for each press and different ranking orders for the individual colors. These results are summarized in Table 7. A composite ranking for each of the colors was calculated and is shown in Table 8.

The researchers observed that there were distinct differences in color uniformity between several of the printed samples, but no systematic attempt was made to calibrate the subjective impression of uniformity with the measured differences.

2013 Color Uniformity Study

The 2013 color uniformity study examined the color uniformities of six electrophotographic press systems in comparison to the color uniformities of a sheetfed lithographic press and an inkjet color proofing device. The hypothesis was that the electrophotographic presses would have color uniformity (calculated as an index) equal to that of a lithographic press. The study supported this hypothesis for one of the electrophotographic presses. Four of the other electrophotographic presses were close but had lower color uniformity indices than the lithographic press. One electrophotographic press in the study had significantly worse color uniformity than all the others. The inkjet proofing device had superior color uniformity compared to any of the other presses in the study, including the lithographic press.

With respect to value and saturation, it was found that of the 96 colors tested, the least uniform colors for the electrophotographic presses were lighter than the least uniform colors for lithography, but for both reproduction methods the colors of lowest uniformity were similarly low in saturation. The least uniform colors for the inkjet proofer were notably lighter and more saturated than those for either lithography or electrophotography.

Analysis of the unprinted paper patch showed that the electrophotographic presses typically distributed tiny toner particles on these areas. Furthermore, some of the electrophotographic presses imaged small yellow dots on the unprinted substrate.

The 2014 Study

The 2013 study was based on the color differences measured from 96 small patches of colors located at six places on an 11x17-inch test form. The 2014 study measured the uniformity of the press systems when printing large solid areas. It examined eleven colors, each imaged across an entire 11x17-in sheet and measured in 96 distributed spots (the same locations on each sheet).

In this report, color uniformity is understood to result from the interactions of all of the components of a printing system, including the printing press, paper, toner, and other factors. When the authors refer to an electrophotographic press in this study, it is meant to encompass the entire electrophotographic printing system of which the press is a part.

Seven electrophotographic presses were included in this study, and the results are coded with the labels PA through PG. One of the participants submitted two sets of printed samples—one set printed before the press—PC—was cleaned and one after. These two sets of samples are designated as PCb (before cleaning) and PCa (after cleaning).

The uniformity values of the electrophotographic presses were compared with an Epson inkjet proofing system similar to the inkjet proofing system used in the 2013 study. No lithographic samples were available for comparison.

The hypothesis for the study was that the color uniformities of all of the electrophotographic presses would be equal. Based on the results of the 2013 study, it was assumed that the inkjet proofing system would exhibit significantly better color uniformity than the electrophotographic presses.

The Test Form

The test form (Figure 1) was a 48-page file that consisted of 12 pages repeated four times. The page size was 11 x 17 in., with the first of the 12 pages being the form used in the 2013 study. The other 11 pages in the 12-page group consisted of solid colors found to be problematic in that study. Specifically:

- Four of the colors were in the 90th percentile of least uniform colors for electrophotographic printing.
- Three colors were in the 90th percentile for lithography.
- Three were in the 90th percentile for inkjet.
- The last of the 11 color solids was a 260% black solid.

Figure 1. *The 12-page 2014 color uniformity test form.*

Table 1 shows the patch designations of each of the eleven problem colors from the 96-patch color chart used in the 2013 study, along with their CMYK values. Table 1 also shows the printing systems where each of the colors was found to have low uniformity.

	Patch	Cyn	Mag	Yel	Blk
Electrophoto	B7	75	63	63	0
	F2	80	90	20	15
	H3	0	0	0	75
	D2	65	45	25	15
Litho	C4	50	40	40	0
	G9	0	75	75	0
	D10	90	80	20	0
Inkjet	A11	25	0	25	0
	G6	20	80	90	15
	C8	0	25	25	0
	260%	65	58	57	80

Table 1. *Cyan, magenta, yellow, and black values of the test colors.*

Each of the pages containing large solids is labeled at the top with the patch designation, the printing system where the color was problematic, and the CMYK values of the color. For example, one of the pages is labeled *C8 Inkjet: 0%cyan; 25% magenta; 25% yellow; 0% black.*

Experimental Procedure

Each of the participants in the study submitted the 48-page printed file for analysis. The researchers had determined in the 2013 study that electrophotographic presses commonly have a short but distinct warm-up period. Thus, the first set of 12 pages in the 48-page samples was not used for analysis. The second set of 12 pages was analyzed for this study. The third and fourth sets were preserved for further analysis.

Because there is no warm-up period for an inkjet printer, a single set of Epson inkjet proofs (12 pages) was submitted and measured for this study.

All measurements were made with an X-Rite i1 spectrophotometer. The CIELAB values were measured at 96 locations on each 11x17 solid color. Figure 2 shows the pattern of measurement locations. The 96 measurements were made in 12 rows of 8 columns. The row and column designations, as well as the lines separating measurement spots, are added to the illustration for clarification and were not printed on the test pages. The targets in Figure 2 indicate the actual measurement spots that were used.

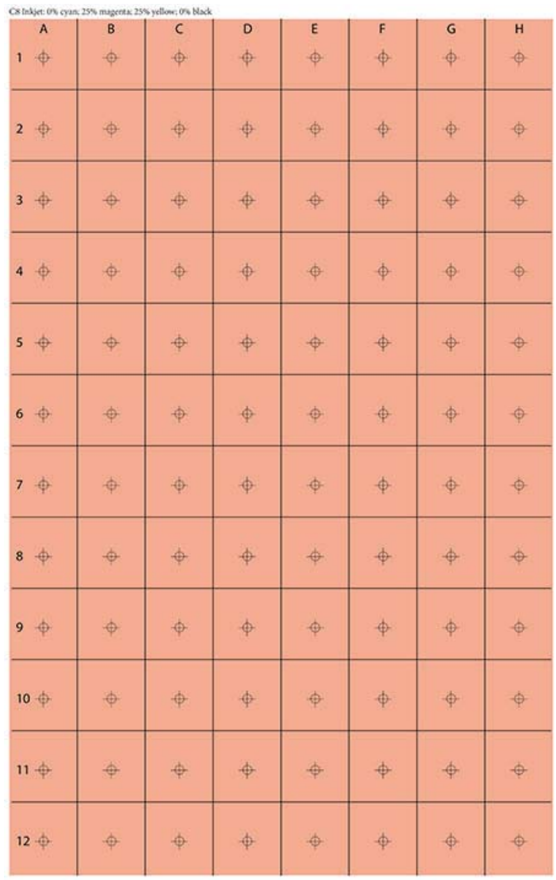


Figure 2. *Measurement locations for each full-page color solid.*

ΔE2000 was chosen as the preferred index for perceptual color difference and is used throughout this study. The CIELAB values of the 96 readings were used to compute ΔE2000 color differences for each of the 4,560 comparative pairs of measurements from a given sheet. A more complete discussion of measurements of perceptual color difference can be found in the 2013 study published in 2013 TAGA Proceedings (Stanton, et al., 2013).

The mean color difference among the 4560 paired comparisons from each solid color was used as the color uniformity index for that sample. Lower average ΔE2000 values indicate greater color uniformity.

The uniformity scores for the eleven colors for each press were averaged to provide an overall color uniformity index for that press system. These values were based on 50,160 measured color differences (11 4560). Having large numbers of readings provided high precision in evaluating color uniformity differences between different colors and press systems.

Color Uniformity Results

The results of color difference analysis for a single press system and color (in this example, press PF and color B7) is shown in Figure 3. Eleven colors for each press system were analyzed in this way. The distribution of ΔE2000 values was positively skewed for all of the press/color combinations. ΔE2000 has a limiting value of zero (meaning no perceived color difference) and, typically, many values were near zero. There were a total of 99 graphic summaries (including the one shown in Figure 3) representing seven different press systems (one with two sets of samples), one proofing system, and 11 test colors. The statistical values were extracted from these 99 conditions and compiled into tables showing the statistics for each press/color combination. These tables are shown in Appendix B.

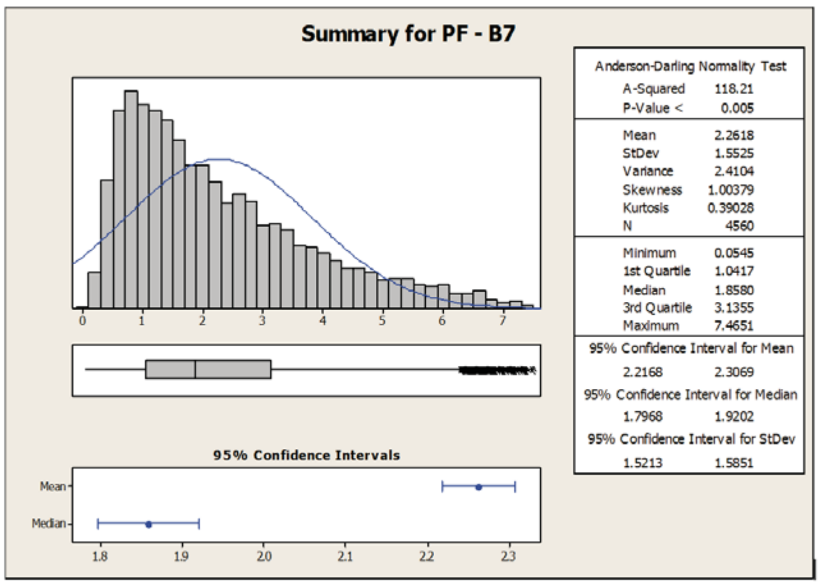


Figure 3. Statistical summary of ΔE2000 values for press PF and color B7.

The mean value in Figure 3 (2.2618) represents the average of 4,560 calculated color differences between all possible pairs of the 96 measured spots on the sheet. This value represents the overall color uniformity of this sheet. Note that the 95% confidence intervals for this mean value have a range of 0.09—less than one-tenth of a ΔE2000 unit. (As a color difference index, one ΔE2000 unit approximates a just-noticeable difference.)

Table 2 shows the mean ΔE2000 values for all of the printing presses and all of the test colors.

	Proof	PE	PA	PD	PG	PCb	PCa	PB	PF
B7	0.43	1.13	1.14	1.50	1.56	2.15	2.17	2.19	2.26
F2	0.19	0.81	0.86	1.01	0.76	1.15	1.28	1.22	1.68
H3	0.46	0.61	0.71	0.95	1.13	1.04	1.19	3.26	2.11
D2	0.26	0.89	0.97	0.83	0.82	1.64	1.66	1.77	2.58
C4	0.39	0.99	0.98	0.90	1.57	1.72	1.75	1.96	2.83
G9	0.24	0.82	0.67	1.25	0.94	1.72	1.99	1.76	0.80
D10	0.26	0.75	1.01	1.14	0.74	1.68	1.67	1.62	1.66
A11	0.27	0.89	0.51	0.71	1.12	0.90	0.94	1.24	0.90
G6	0.30	0.83	0.74	1.09	1.04	1.47	1.67	1.59	1.42
C8	0.32	0.90	0.58	0.92	1.60	1.11	1.26	1.34	1.05
260	0.31	0.68	1.01	1.24	1.02	1.15	1.25	1.90	1.00

Table 2. *Mean ΔE2000 values for all colors and all printing presses. Presses in order from best to worst color uniformity.*

One general observation was made by examining the data in Table 2. The color uniformity of the inkjet proof was noticeably better than all of the electrophotographic presses for every color.

To get a better sense of the relationship of the data, the values in Table 2 were plotted as a 3D graph (Figure 4). The 3D plot clearly reveals substantial differences between the color uniformities of the electrophotographic presses in the study. Furthermore, for some of the presses, there are large differences between the color uniformities of different colors.

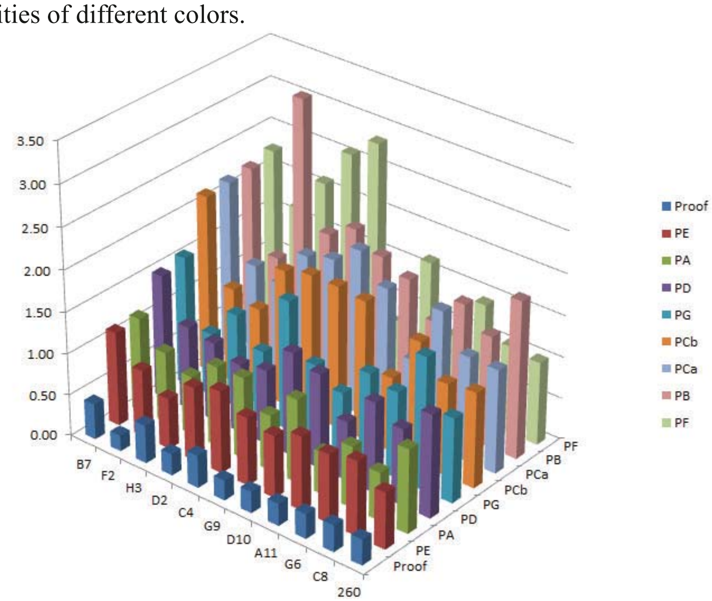


Figure 4. *Mean ΔE2000 values plotted by color and press system.*

The analysis of variance technique was used to test the significance of the differences of color uniformity between the different presses in this study. The large sample size and other characteristics of the data in this study fall within acceptable parameters for using F-tests. The samples in this study are independent and can be re-ordered without losing information. The sample sizes are all balanced and the distributions are all similarly skewed towards the low values.

When all the color uniformity values for all the test colors for a given press system were combined to calculate an overall value, there were 50,160 calculated ΔE2000 values for each press. The summary statistics for press PA are shown in Figure 5. The summary statistics for all of the presses are shown in Appendix C.

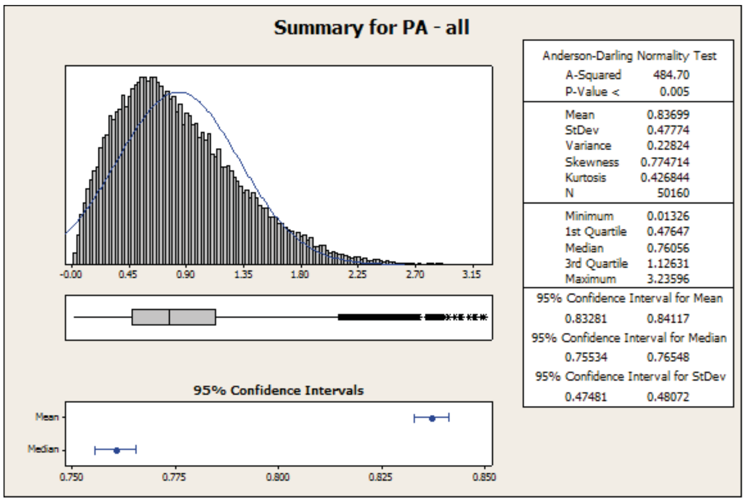


Figure 5. *Statistical summary of ΔE2000 values for press PA and all colors.*

The summary ANOVA report examining whether there were significant differences between presses with respect to color uniformity overall is shown in Figure 6. Later, further ANOVAs were used to investigate whether the colors themselves influenced the color uniformity of the various presses.

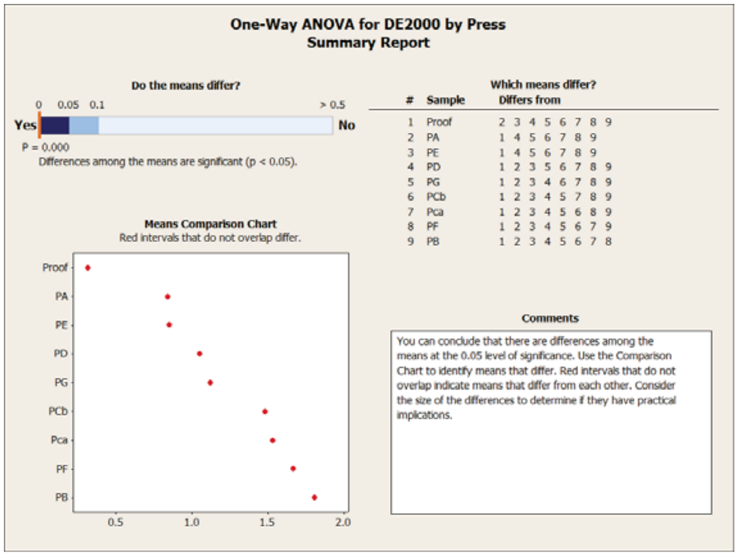
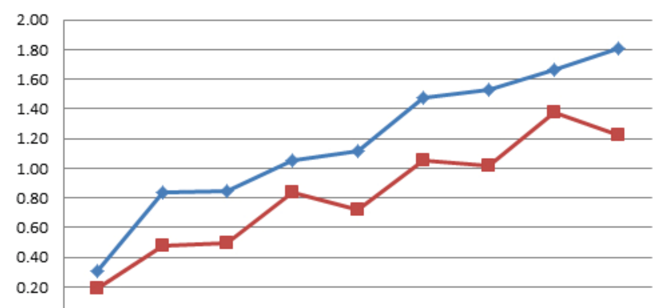


Figure 6. *ANOVA summary of overall color uniformity for all presses.*

Because of the very large sample sizes in this ANOVA, highly precise estimates of the mean color difference values were achieved. This enabled significant differences to be identified between most of the presses in the study. Only presses PA and PE were found to have equal color uniformities. These two presses had the best color uniformities of any of the electrophotographic presses in the study.

It is noteworthy that, as hypothesized, the inkjet proofing device had markedly better color uniformity than any of the electrophotographic presses in the study. This finding is consistent with the findings of the 2013 study.

Figure 7 shows the rank order of the presses (left to right), together with the mean ΔE2000 values and the standard deviations of color differences.



	Proof	PA	PE	PD	PG	PCb	PCa	PF	PB
Mean	0.31	0.84	0.85	1.05	1.12	1.48	1.53	1.66	1.80
Std dev	0.19	0.48	0.50	0.84	0.72	1.05	1.02	1.38	1.22

Figure 7. *Presses in order of greater to lesser overall color uniformity, with mean ΔE2000 values and standard deviations.*

The color uniformity of presses PA and PE were statistically equal and were the best in the study. The other six presses finished in the following order: PD, PG, PC, PF, and PB. It is interesting that the PC press had better color uniformity before cleaning and maintenance was performed (PCb) than after (PCa).

It is noteworthy that the range of means for all of the electrophotographic presses was less than one ΔE2000 unit, approximately equivalent to a just-noticeable difference. Measurements give accurate calculations of color uniformity, but it would require subjective analysis to gauge the visual impact of the measured differences. Such analysis was not part of this study.

The standard deviation values indicate the average ΔE2000 variation expected between two randomly selected points on the sheet. Typically, lower average mean ΔE2000 scores are associated with lower standard deviations. However, there are two instances (PD and PF) where the standard deviations are higher relative to the means. Examination of the distribution curves in Appendix C shows that these two distributions have similar shapes with relatively large numbers of outliers compared to the other presses.

Appendix D shows the skewness and kurtosis values for each of the press/color combinations and for each press across all colors. Examination of these data revealed that press PD had an extremely high kurtosis value compared to the other presses. Further investigation revealed that some of the colors solids from the PD press exhibited pronounced horizontal streaks. This phenomenon was further investigated with surface plots as described later.

Mann-Whitney Test

A series of Mann-Whitney tests was used to compare the equality of color uniformity score medians for the different presses in this study. Mann-Whitney is a nonparametric statistic that assumes the data are independent random samples from two populations that have the same shape. This test was used as a check on the validity of the findings from the ANOVA. Table 4 shows the results of the Mann-Whitney tests together with the median values for each press.

Median		PA	PB	Pca	PCb	PD	PE	PF	PG
0.28	Proof	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.76	PA		0.00	0.00	0.00	0.00	0.62	0.00	0.00
1.57	PB			0.00	0.00	0.00	0.00	0.00	0.00
1.31	PCa				0.00	0.00	0.00	0.04	0.00
1.21	PCb					0.00	0.00	0.00	0.00
0.89	PD						0.00	0.00	0.00
0.76	PE							0.00	0.00
1.24	PF								0.00
0.96	PG								

Table 4. *Mann-Whitney test of equality of medians for each press.*

The Mann-Whitney results did not support a difference between the medians of PA and PE, but had high confidence in rejecting the hypotheses that any of the other medians were equal. The comparison of medians between PF and PCa yielded a p-value of 0.04, which was below the 0.05 alpha level chosen for the analysis. Each press had 50,160 calculated ΔE2000 values resulting in very tight confidence intervals around the estimates of median values.

The Mann-Whitney findings supported the finding from the ANOVA analysis that the only presses in the study that had equal mean values were PA and PE.

Color Uniformities of Individual Colors

After the color uniformity scores of presses across all colors were tested, the uniformities of individual colors across all presses was examined to determine if some test colors resulted in better uniformity overall than others. A one-factor ANOVA was used to test if there were significant differences between the color uniformity scores of the test colors. The summary report from the ANOVA is shown in Figure 8.

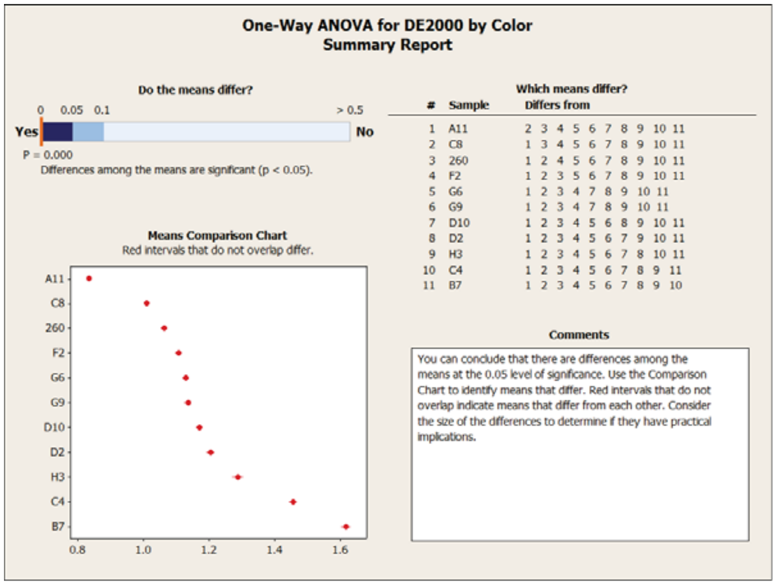


Figure 8. *ANOVA summary for effect of color on DE2000 color difference scores.*

The ANOVA showed significant differences between the test colors and the overall color uniformity scores with the exception of the colors G6 and G9 which were found to have the same color uniformity scores across presses.

Table 5 shows the colors in order from the best to worst color uniformities across all presses. The table also contains the mean ΔE2000 values for each color and the processes for which the colors had relatively poor color uniformity in the 2013 study. (Stanton, et al, 2013).

Rank	Color	Mean	90th percentile
1	A11	0.83	Inkjet
2	C8	1.01	Inkjet
3	260	1.06	
4	F2	1.11	Electrophotography
5	G6	1.13	Inkjet
	G9	1.13	Lithography
7	D10	1.17	Lithography
8	D2	1.20	Electrophotography
9	H3	1.27	Electrophotography
10	C4	1.45	Lithography
11	B7	1.62	Electrophotography

Table 5. *Individual colors in order of most to least uniform across all presses (2014 study), as well as the mean ΔE2000 values for each color and the processes for which the colors had relatively poor color uniformity (2013 study).*

It is interesting to note that the colors that were problematic for electrophotography in the 2013 study tended to have poor color uniformity scores in this study as well. The colors that were above the 90th percentile for inkjet in 2013 were among the most uniform colors in this study.

Influence of Color on Individual Press Output

It was determined that the test colors themselves had significant influence on the uniformity scores for all presses as a group, but it was of greater interest to examine the influence of the test colors on each of the press systems. Two research questions were posed. First, were the test colors significant factors on the color uniformity for all of the presses in the study? Second, was there consistency between the electrophotographic presses in term of which colors had higher or lower color uniformity scores?

To address the influence of test colors on individual presses, one-factor ANOVAs were performed for each of the presses in the study. The summaries of these ANOVAs are contained in Appendix E along with the Tukey analysis showing which colors are significantly different from the others.

Table 6 shows the F-ratios, P-values, and R-squared values for each of the presses.

	F-ratio	P-value	R squared
Inkjet	1103.12	0.00	18.03
PA	996.73	0.00	16.58
PB	1248.51	0.00	19.93
PCb	810.36	0.00	13.91
PCa	698.38	0.00	19.93
PD	342.68	0.00	6.40
PE	400.77	0.00	7.40
PF	1566.18	0.00	23.80
PG	1121.06	0.00	18.27

Table 6. *Results from one-factor ANOVAs testing the influence of test colors on the color uniformity of presses.*

The P-values in Table 6 show high confidence that the colors had significant influence on the color uniformity scores. The Tukey analysis showed that for each press some colors had equal influence on color uniformity scores, while others had significantly different influence.

Table 7 shows for each press a summary of the colors in order of their uniformities from least to most, along with their mean ΔE2000 values and their ranks from least to most influence on uniformity.

PA			PB			PCb			PCa		
color	mean	rank	color	mean	rank	color	mean	rank	color	mean	rank
B7	1.14	1.0	H3	3.26	1.0	B7	2.15	1.0	B7	2.17	1.0
D10	1.01	2.5	B7	2.19	2.0	G9	1.72	3.0	G9	1.99	2.0
BLK	1.01	2.5	C4	1.96	3.5	C4	1.72	3.0	C4	1.75	3.0
C4	0.98	4.5	BLK	1.90	3.5	D10	1.68	3.0	G6	1.67	5.0
D2	0.97	4.5	D2	1.77	5.5	D2	1.64	5.0	D10	1.67	5.0
F2	0.86	6.0	G9	1.76	5.5	G6	1.47	6.0	D2	1.66	5.0
G6	0.74	7.5	D10	1.61	7.5	F2	1.15	8.0	F2	1.28	8.0
H3	0.71	7.5	G6	1.59	7.5	BLK	1.15	8.0	C8	1.26	8.0
G9	0.69	9.0	C8	1.34	9.0	C8	1.11	8.0	BLK	1.25	8.0
C8	0.58	10.0	A11	1.24	10.5	H3	1.04	10.0	H3	1.19	10.0
A11	0.51	11.0	F2	1.22	10.5	A11	0.90	11.0	A11	0.94	11.0

PD			PE			PF			PG		
color	mean	rank	color	mean	rank	color	mean	rank	color	mean	rank
B7	1.50	1.0	B7	1.13	1.0	C4	2.83	1.0	C8	1.60	2.0
G9	1.25	2.5	C4	0.99	2.0	D2	2.58	2.0	C4	1.57	2.0
BLK	1.24	2.5	C8	0.90	4.0	B7	2.26	3.0	B7	1.56	2.0
D10	1.14	5.0	A11	0.89	4.0	H3	2.11	4.0	H3	1.13	4.5
G6	1.09	5.0	D2	0.89	4.0	F2	1.68	5.5	A11	1.12	4.5
F2	1.01	5.0	G6	0.83	7.0	D10	1.66	5.5	G6	1.04	6.5
H3	0.95	8.0	G9	0.82	7.0	G6	1.42	7.0	BLK	1.02	6.5
C8	0.92	8.0	F2	0.81	7.0	C8	1.05	8.5	G9	0.94	8.0
C4	0.90	8.0	D10	0.75	9.0	BLK	1.00	8.5	D2	0.82	9.0
D2	0.83	10.0	BLK	0.68	10.0	A11	0.90	10.0	F2	0.76	10.5
A11	0.71	11.0	H3	0.61	11.0	G9	0.80	11.0	D10	0.74	10.5

Table 7. *For each press, the colors in order of their uniformity and the rank in terms of influence on color uniformity.*

Table 7 contains only the data from the electrophotographic presses in the study because the influences of color on inkjet are different than they are on electrophotography. The rankings have been assigned such that colors whose uniformity is relatively the same are all given the same rank. The order of the ranking is from lower (1) to higher (11) color uniformity, so high-ranking numbers represent colors that are less problematic for a given press.

The mean values in Table 7 are the average ΔE2000 color differences measured between all the pair combinations from the 96 measurement sites on each sheet. The measurement sites were the same for all of the different colors. As seen previously, some of the electrophotographic presses had higher average color differences than others.

The boxplots for each press are shown in Appendix F. These plots show the relationships between the 4,560 calculated ΔE2000 values for each color/press combination. They are useful for gauging the range of ΔE2000 values for each color and the relative numbers of outliers.

Table 7 shows that the ranking order of the colors varies between different electrophotographic presses, but the variation does not appear to be random. A composite ranking was calculated for each of the colors to determine which colors were associated with higher or lower color uniformity scores. These results are shown in Table 8 along with the ranking order of colors for the inkjet proof.

Rank	Electro		Inkjet	
1	A11		F2	
2	F2		G9	
3	C8		D10	
4	H3		D2	
5	G6		A11	
6	260		G6	
7	G9		260	
8	D10		C8	
9	D2		C4	
10	C4		B7	
11	B7		H3	

Table 8. *Composite ranking of the colors for electrophotography and inkjet, in this case, with 1 being most uniform and 11 being least uniform.*

The ranking order in Table 8 (unlike Table 7) is with low numbers representing a high degree of color uniformity and high numbers meaning less color uniformity. There are slight differences between the electrophotographic rankings in Table 8 and those in Table 5. This is due to the higher mean ΔE2000 values with some electrophotographic presses than others. When all of the presses were pooled (Table 5) the presses with lower color uniformities (higher mean ΔE2000 values) had greater influence on the rankings.

Color Streaks

One of the most pronounced observations that the researchers made from the samples submitted for the 2014 study was that some press/color combinations showed pronounced streaks, usually in the vertical orientation. The streaks were not observed in the 2013 study, which examined the uniformity of small color patches located in six places across the 11x17-in. test form. The current study was designed to measure large samples of uniform color for two reasons. It allowed the measurement of as many locations as practical. It also mimicked the common commercial need to print large color solids for advertising materials. Figure 9 shows a photograph depicting the top of a vertical streak at the on of a sample.

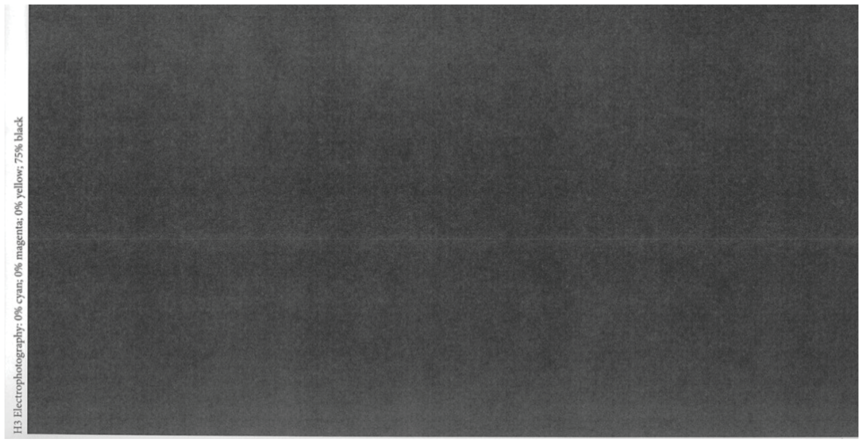


Figure 9. *Photograph showing section of a vertical streak (the sheet has been turned to save space).*

Some streaks were darker than the surrounding area; others were lighter. Viewing the entire page, the streaks were a distinct defect that many customers would find objectionable. In an effort to characterize the streaks, three-dimensional surface graphs were made from some of the samples. Even when streaking was not captured by the surface plots, they provided a good visual confirmation of the color uniformity of the presses.

Figure 10 shows surface plots from an inkjet sample that exhibited a high color uniformity score (left) and from an electrophotographic print that exhibited moderately high color uniformity (right).

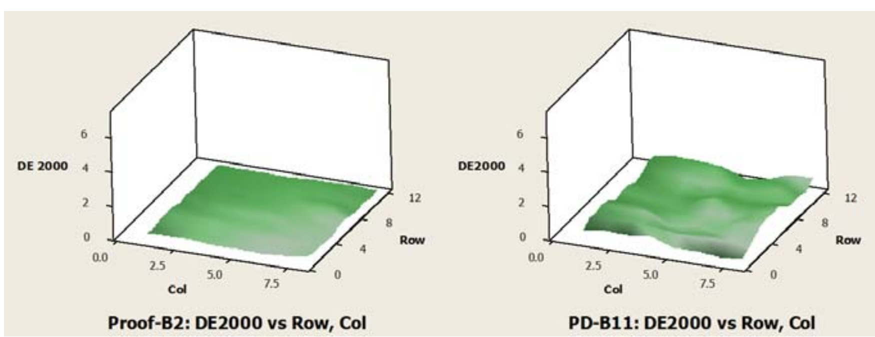


Figure 10. *Surface plots of inkjet and electrophotographic prints.*

As seen in Figure 10, the inkjet samples had good color uniformity resulting in a nearly flat surface, while the electrophotographic print had lower color uniformity resulting in more undulations in the surface.

The surface plots were made from 96 calculated ΔE2000 color difference values. The CIELAB values from each measured spot were compared with the mean CIELAB values from the whole sheet. Since the measurements were made in 12 rows of 8 columns, the surface plot was constructed with ΔE2000 color difference as the response variable plotted against reading locations (the rows and columns into which each sheet was divided). Figure 11 shows a surface plot from a sample where some pronounced streaking was seen. The figure also shows the distribution of ΔE2000 values from that sheet.

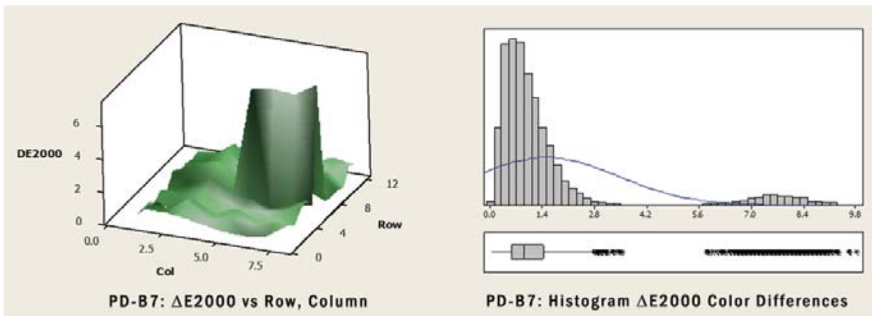


Figure 10. *Surface plot and histogram of sample with distinct streaks.*

The histogram for press PD and color B7 was not typical of the other press/color combinations. This can be confirmed by examining the boxplots for all the press/color combinations shown in Appendix F. The bimodal distribution was due to the streaks on that sample.

A section of one streak is captured dramatically in the surface plot in Figure 10. It was chance that the surface plot measurements captured the streak. The reading aperture of the i1 spectrophotometer used for the measurements was 1/8-in. and the readings were spaced approximately every 1.4 inches both horizontally and vertically. Therefore, the probability of the measurements coinciding with the streaks was small.

The authors are considering means to objectively measure the presence of streaks as a follow-up study because they are objectionable artifacts in the printing of solid colors.

Conclusions

This study examined the color uniformity of seven electrophotographic press systems compared to the color uniformity of an Epson inkjet proofing device. One of the electrophotographic presses was tested under two different conditions: before and after cleaning and maintenance.

The CIELAB values of eleven 11x17-inch test pages, each filled with a solid color, were measured for each press. The measurements were made at the same 96 locations on each sheet. The measurements were arranged as 12 rows and 8 columns.

The colors were chosen based on their performance in the earlier study of color uniformity by Stanton, Bohan, and Ferrari (2013). Large solid-color areas allowed for comprehensive measurements of color uniformity and mimicked a common requirement in advertising printing.

The color uniformity index was based on ΔE2000 color difference values from all of the paired comparisons from 96 uniformly-spaced CIELAB measurements that were made from each sheet—4,560 comparison pairs per sheet. The ΔE2000 values represent calculated differences between two color samples on a scale correlated to human perception. The relationship is designed such that one ΔE2000 unit equates to a just-noticeable difference for a standard human observer under a defined light source.

The mean of the 4,560 ΔE2000 values for a given sheet yielded the color uniformity score. Lower mean values indicate a color solid that is more uniform in color. For each press in the study, the average of the color uniformity scores for the 11 colors included in the study represented the overall color uniformity score. The uniformity scores for each of the presses were based on 50,160 calculated ΔE2000 values.

The hypothesis of the study was that the color uniformity scores for all of the electrophotographic presses would be equal and that the uniformity of the individual colors would also be equal. Based on the 2013 study, it was assumed that the inkjet proofing device would have better color uniformity than the electrophotographic presses. ANOVA testing revealed that the color uniformities of the electrophotographic presses were significantly different from one another with the exception of presses PA and PE, which were found to be equal. These two presses also had the best color uniformity of the electrophotographic presses. The range of mean ΔE2000 values among all the electrophotographic presses was 0.96. As expected, the inkjet proofing device had significantly better color uniformity than any of the electrophotographic presses.

The color uniformities for individual colors across all electrophotographic presses were also found to be different from each other with the exception of two colors: G6 and G9, the two colors in the study from the red domain. The ranking of the colors in order for most to least color uniformity is shown in Table 5. Overall, the pastel colors had the best color uniformity, while darker, near-neutral colors were among the worst.

When individual presses were tested to see whether any colors were associated with greater or lesser uniformity, the results were complex. There were different equal and unequal colors for each press and different ranking orders for the individual colors. These results are summarized in Table 7. A composite ranking for each of the colors to indicate its overall association with color uniformity was calculated and is shown in Table 8.

The use of large color solids for this study revealed the presence of streaks that were not detected in the 2013 study. The streaks were usually oriented in the vertical direction which is the direction of printing for electrophotographic presses. When viewing the sheet, the streaks were easily seen and would be objectionable to many customers. The researchers feel that further study is needed to objectively measure and characterize the occurrence of streaks in large printed solids.

References

Stanton A., Bohan M. and Ferrari, L, Color Uniformity of Digital Presses, TAGA Proceedings, pp. 237–275, 2013.

Hogg, Robert V., and Tanis, Elliot, Probability and Statistical Inference, 8th edition, Pearson, 2008.

Wasserman, Larry, All of Statistics, A Concise Course in Statistical Inference, Springer Science+Business Media, Inc., New York, NY, 2005.

Appendix A

CMYK values for 96-patch color field.

	A		B		C		D		E		F		G		H	
1	0	0	10	50	25	25	100	100	40	5	10	4	100	0	0	3
	25	0	25	0	25	0	100	100	30	0	10	0	100	0	0	0
2	25	17	25	50	80	20	65	45	20	90	80	90	0	50	90	20
	17	0	10	0	90	0	25	15	80	0	20	15	0	0	80	0
3	0	0	50	25	17	10	25	25	74	63	25	10	50	10	0	0
	97	0	10	5	25	0	0	0	63	100	17	0	25	5	0	75
4	17	25	90	20	50	40	80	90	65	25	20	90	0	0	5	40
	10	0	80	15	40	0	20	0	45	0	80	15	0	0	30	0
5	5	30	80	70	0	0	0	0	0	100	65	25	25	50	100	90
	40	0	70	100	75	0	3	0	0	0	45	15	10	5	15	0
6	100	100	10	17	15	100	97	0	50	50	25	0	20	80	10	6
	0	0	25	0	90	0	0	0	0	0	0	0	90	15	6	0
7	90	80	75	63	75	75	0	25	25	10	100	0	10	17	0	0
	80	100	63	0	0	0	0	0	50	5	0	0	25	0	50	0
8	30	40	0	0	0	25	0	0	0	0	10	25	0	75	0	50
	5	0	0	100	25	0	0	25	0	97	50	5	0	0	50	0
9	10	10	50	10	0	97	75	0	0	0	90	15	0	75	0	0
	4	0	25	0	0	0	75	0	0	50	100	0	75	0	0	3
10	90	80	50	25	75	0	90	80	65	45	3	0	65	58	10	50
	20	15	10	0	0	0	20	0	25	0	0	0	57	80	25	5
11	25	0	0	100	50	0	40	30	30	5	100	100	25	17	0	0
	25	0	100	0	50	0	5	0	40	0	100	0	10	0	100	0
12	25	10	50	50	20	80	80	20	75	75	4	10	10	25	50	0
	50	0	50	0	90	0	90	15	75	0	10	0	50	0	0	0

Order of values in each patch: {cyan, magenta}
{yellow, black}

Appendix B

Statistical values for each test color and press combination.

Inkjet Proof

Colors		mean	std dev	variance	skew	kurt
	B7	0.43	0.23	0.05	0.83	0.49
	F2	0.19	0.10	0.01	0.72	0.28
	H3	0.46	0.24	0.06	0.94	0.98
	D2	0.26	0.13	0.02	0.62	0.06
	C4	0.39	0.18	0.03	0.66	0.14
	G9	0.24	0.13	0.02	0.66	0.29
	D10	0.26	0.14	0.02	0.90	0.89
	A11	0.27	0.15	0.02	0.78	0.44
	G6	0.30	0.17	0.03	0.70	0.14
	C8	0.32	0.17	0.03	0.59	-0.06
	260	0.31	0.15	0.02	0.99	1.56
	Avg.	0.31	0.16	0.03	0.76	0.47

Appendix B (continued)

Statistical values for each test color and press combination.

Electrophotographic Press PA

Colors		mean	std dev	variance	skew	kurt
	B7	1.14	0.49	0.24	0.35	-0.21
	F2	0.86	0.46	0.21	0.63	0.09
	H3	0.71	0.51	0.26	0.87	0.34
	D2	0.97	0.48	0.23	0.46	-0.27
	C4	0.98	0.45	0.20	0.61	0.28
	G9	0.67	0.36	0.13	0.66	0.23
	D10	1.01	0.54	0.29	0.65	0.33
	A11	0.51	0.27	0.07	0.75	0.54
	G6	0.74	0.41	0.17	0.68	0.04
	C8	0.58	0.29	0.08	0.50	-0.08
	260	1.01	0.47	0.22	0.73	0.45
	Avg.	0.83	0.43	0.19	0.63	0.16

Electrophotographic Press PB

Colors		mean	std dev	variance	skew	kurt
	B7	2.19	1.00	1.00	0.18	-0.67
	F2	1.22	0.68	0.47	0.69	-0.11
	H3	3.26	2.29	5.26	0.63	-0.51
	D2	1.77	0.88	0.78	0.46	-0.23
	C4	1.96	0.91	0.82	0.46	-0.22
	G9	1.76	1.02	1.04	0.44	-0.68
	D10	1.62	0.87	0.75	0.45	-0.49
	A11	1.24	0.72	0.52	0.67	-0.14
	G6	1.59	0.89	0.80	0.37	-0.83
	C8	1.34	0.72	0.52	0.39	-0.62
	260	1.90	1.10	1.22	0.72	-0.25
	Avg.	1.80	1.01	1.20	0.50	-0.43

Appendix B (continued)

Statistical values for each test color and press combination.

Electrophotographic Press PCb

Colors		mean	std dev	variance	skew	kurt
	B7	2.15	1.29	1.68	0.75	-0.06
	F2	1.15	0.66	0.44	0.50	-0.48
	H3	1.04	0.78	0.60	1.21	1.76
	D2	1.64	0.91	0.83	0.50	-0.43
	C4	1.72	0.99	0.98	0.69	-0.19
	G9	1.72	1.19	1.42	0.86	-0.08
	D10	1.68	0.99	0.98	0.30	-1.06
	A11	0.90	0.54	0.29	0.81	0.13
	G6	1.47	1.09	1.19	0.83	-0.19
	C8	1.11	0.67	0.48	0.80	0.19
	260	1.15	0.58	0.33	0.59	-0.17
	Avg.	1.43	0.88	0.84	0.71	-0.05

Electrophotographic Press PCa

Colors		mean	std dev	variance	skew	kurt
	B7	2.17	1.23	1.52	0.57	-0.38
	F2	1.28	0.68	0.46	0.53	-0.09
	H3	1.19	0.89	0.79	1.08	1.11
	D2	1.66	0.90	0.82	0.58	-0.17
	C4	1.75	1.03	1.06	0.82	0.14
	G9	1.99	1.41	2.00	0.95	0.20
	D10	1.67	0.92	0.84	0.32	-0.84
	A11	0.94	0.60	0.35	0.84	0.07
	G6	1.67	1.13	1.28	0.96	0.36
	C8	1.26	0.73	0.53	0.71	-0.08
	260	1.25	0.63	0.40	0.55	-0.13
	Avg.	1.53	0.92	0.91	0.72	0.02

Appendix B (continued)

Statistical values for each test color and press combination.

Electrophotographic Press PD

Colors		mean	std dev	variance	skew	kurt
	B7	1.50	1.93	3.73	2.75	6.47
	F2	1.01	0.53	0.28	0.56	-0.12
	H3	0.95	0.79	0.62	1.58	3.58
	D2	0.83	0.48	0.23	0.89	0.57
	C4	0.90	0.46	0.21	0.77	0.33
	G9	1.25	0.72	0.51	0.86	0.62
	D10	1.14	0.58	0.33	0.54	0.01
	A11	0.71	0.38	0.15	0.64	0.07
	G6	1.09	0.60	0.36	0.75	0.38
	C8	0.92	0.51	0.26	0.78	0.48
	260	1.24	0.79	0.63	1.21	1.60
	Avg.	1.05	0.71	0.66	1.03	1.27

Electrophotographic Press PE

Colors		mean	std dev	variance	skew	kurt
	B7	1.13	0.60	0.36	0.71	0.19
	F2	0.81	0.43	0.19	0.61	0.06
	H3	0.61	0.42	0.18	0.91	0.49
	D2	0.89	0.51	0.26	0.90	0.81
	C4	0.99	0.53	0.28	0.91	0.67
	G9	0.82	0.46	0.21	0.94	1.22
	D10	0.75	0.41	0.17	0.78	0.62
	A11	0.89	0.52	0.27	0.85	0.57
	G6	0.83	0.54	0.29	1.36	2.36
	C8	0.90	0.48	0.23	0.69	0.18
	260	0.68	0.32	0.10	0.74	0.64
	Avg.	0.85	0.47	0.23	0.85	0.71

Appendix B (continued)

Statistical values for each test color and press combination.

Electrophotographic Press PF

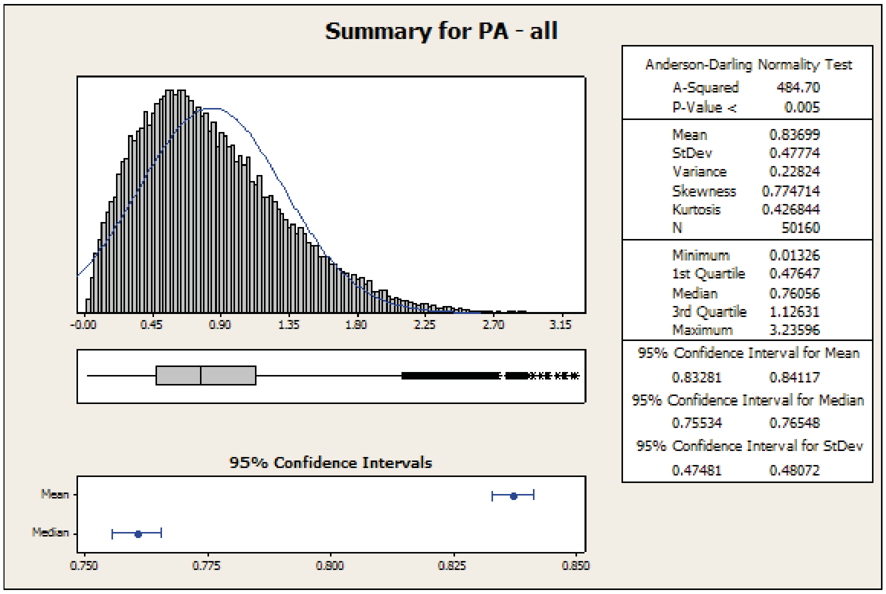
Colors		mean	std dev	variance	skew	kurt
	B7	2.26	1.55	2.41	1.00	0.39
	F2	1.68	1.04	1.09	0.82	0.10
	H3	2.11	1.69	2.85	0.90	-0.15
	D2	2.58	1.80	3.23	0.93	0.33
	C4	2.83	1.84	3.39	0.83	0.10
	G9	0.80	0.48	0.23	0.74	0.14
	D10	1.66	0.94	0.88	0.63	-0.18
	A11	0.90	0.48	0.23	0.63	-0.01
	G6	1.42	0.91	0.83	0.71	-0.22
	C8	1.05	0.61	0.37	0.88	0.62
	260	1.00	0.66	0.44	1.16	0.84
	Avg.	1.66	1.09	1.45	0.84	0.18

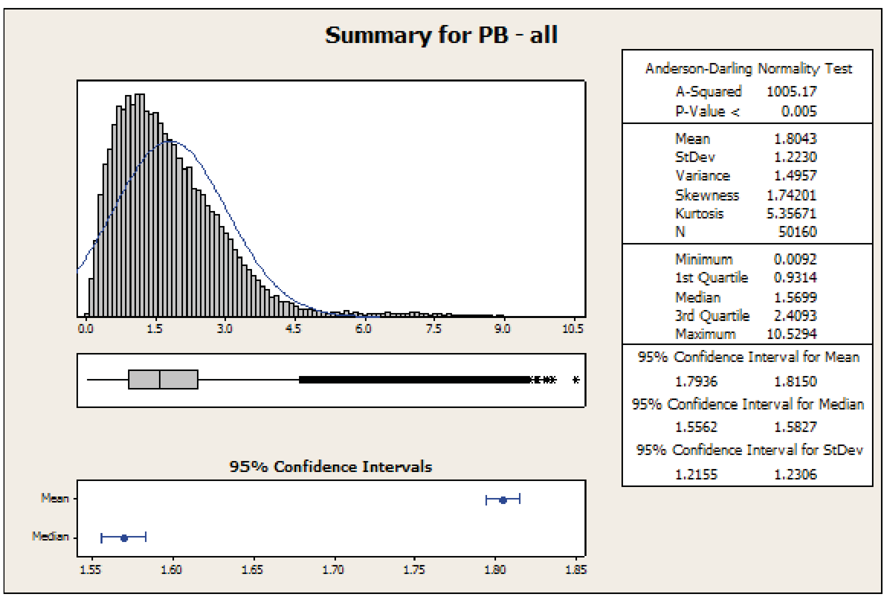
Electrophotographic Press PG

Colors		mean	std dev	variance	skew	kurt
	B7	1.56	0.88	0.77	0.69	-0.19
	F2	0.76	0.39	0.15	0.42	-0.36
	H3	1.13	0.80	0.64	0.77	0.01
	D2	0.82	0.43	0.19	0.72	0.21
	C4	1.57	0.83	0.69	0.66	-0.16
	G9	0.94	0.50	0.25	0.68	0.29
	D10	0.74	0.39	0.15	0.63	0.10
	A11	1.12	0.62	0.38	0.63	0.01
	G6	1.04	0.50	0.25	0.35	-0.34
	C8	1.60	0.98	0.97	0.67	-0.28
	260	1.02	0.47	0.22	0.52	-0.09
	Avg.	1.12	0.62	0.42	0.61	-0.07

Appendix C

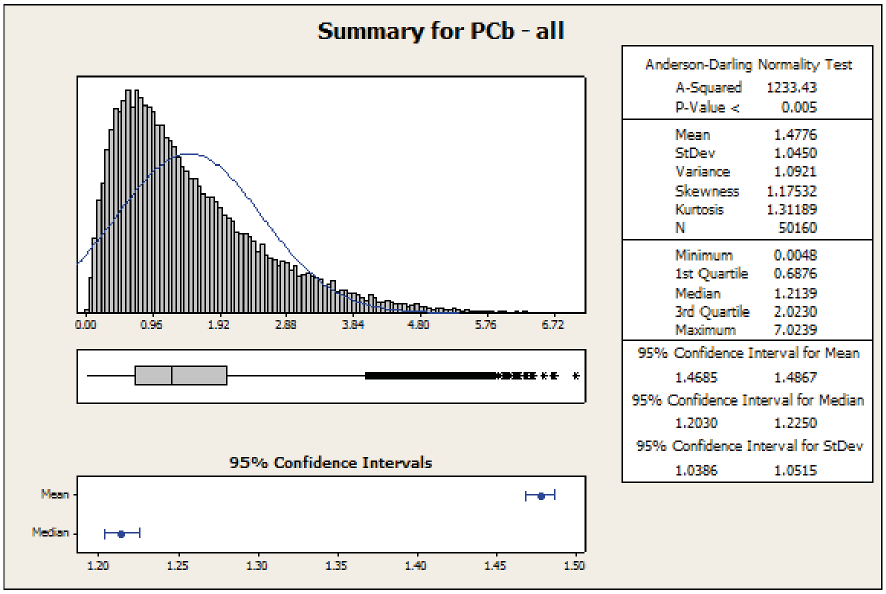
Statistical summaries of ΔE2000 values for all colors with each press system.

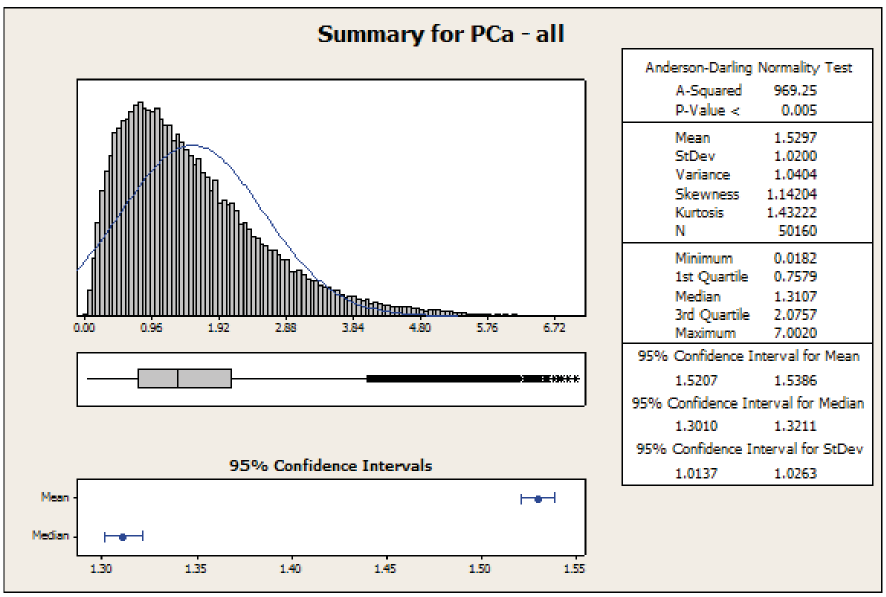




Appendix C

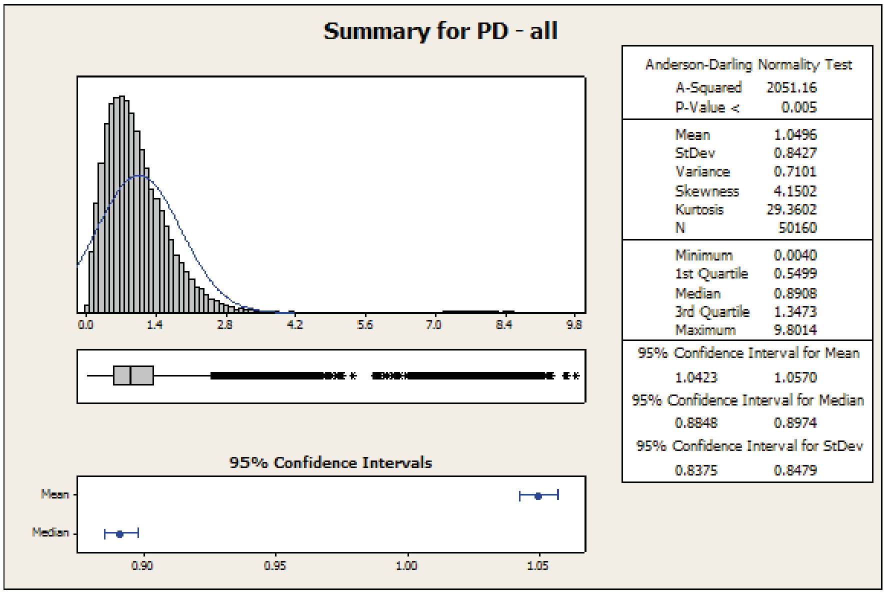
Statistical summaries of ΔE2000 values for all colors with each press system.

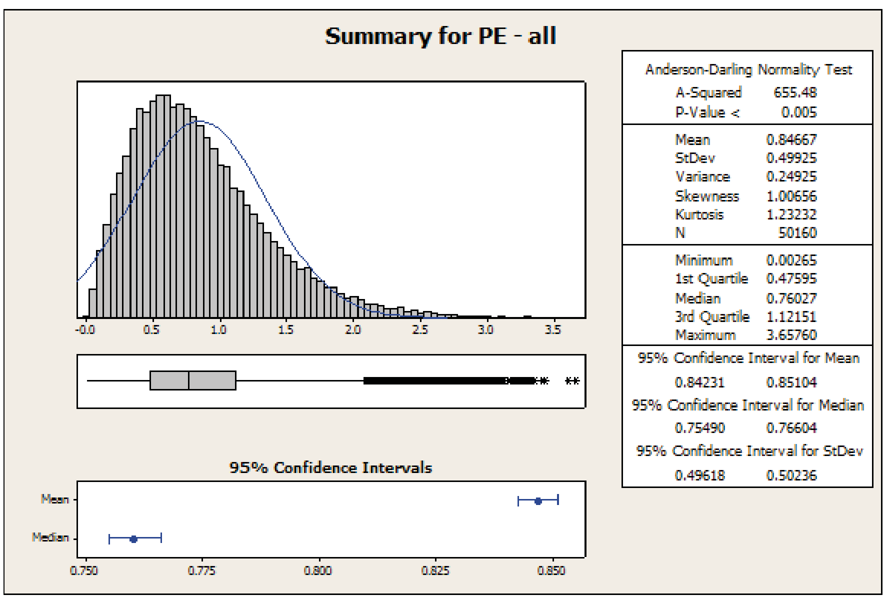




Appendix C

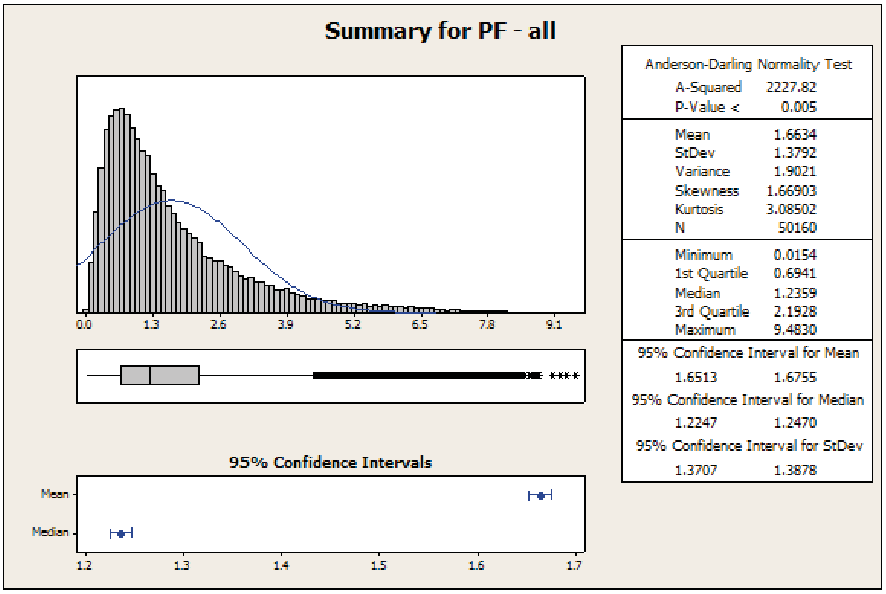
Statistical summaries of ΔE2000 values for all colors with each press system.

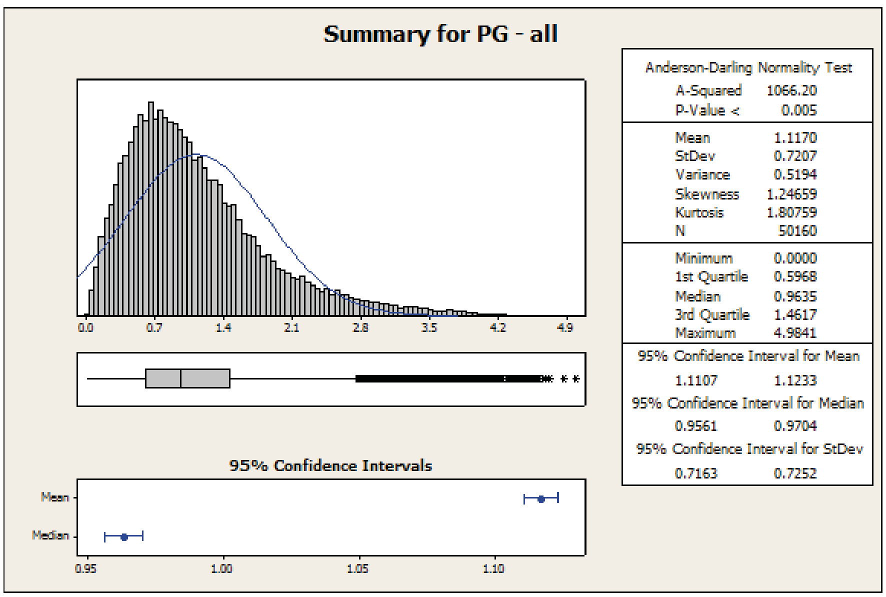




Appendix C

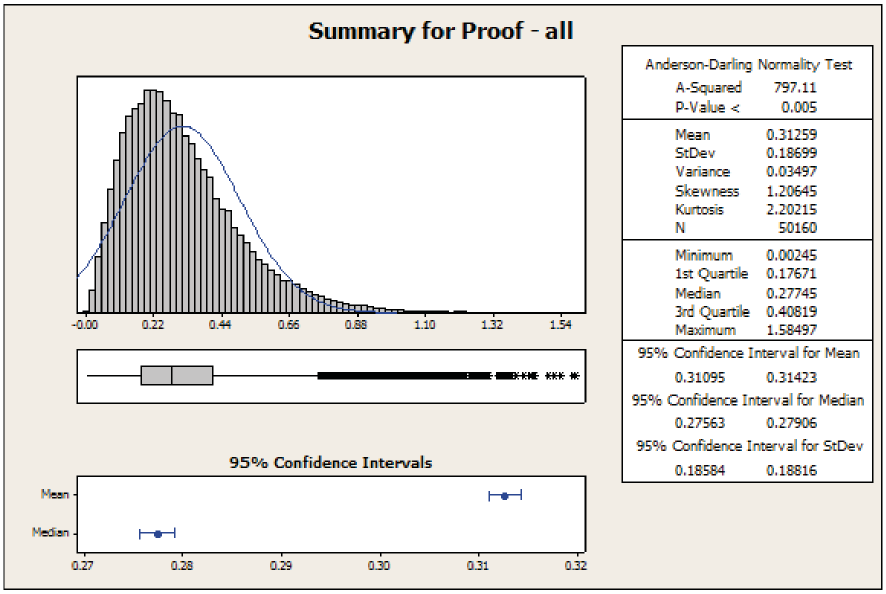
Statistical summaries of ΔE2000 values for all colors with each press system.





Appendix C

Statistical summaries of ΔE2000 values for all colors with each press system.



Appendix D

Skewness and kurtosis values for each press/color combination and for each press across all colors.

		Proof	PA	PB	PCa	PCb	PD	PE	PF	PG
B7	Skew	0.83	0.35	0.18	0.57	1.68	3.73	0.71	1.00	0.69
	Kurt	0.49	-0.21	-0.67	-0.38	-0.06	2.75	0.19	0.39	-0.19
F2	Skew	0.72	0.63	0.69	0.53	0.50	0.56	0.61	0.82	0.42
	Kurt	0.28	0.09	-0.11	-0.09	-0.48	-0.12	-0.06	0.10	-0.36
H3	Skew	0.94	0.26	0.63	1.08	1.21	1.58	0.91	0.90	0.77
	Kurt	0.98	0.87	-0.51	1.11	1.76	3.58	0.49	-0.15	0.01
D2	Skew	0.62	0.46	0.46	0.58	0.50	0.89	0.90	0.93	0.72
	Kurt	0.06	-0.27	-0.23	-0.17	-0.43	0.57	0.81	0.33	0.21
C4	Skew	0.66	0.61	0.46	0.82	0.69	0.77	0.91	0.83	0.66
	Kurt	0.14	0.28	-0.22	0.14	-0.19	0.33	0.67	0.10	-0.16
G9	Skew	0.66	0.13	0.44	0.95	0.86	0.86	0.94	0.74	0.68
	Kurt	0.29	0.23	-0.68	0.20	-0.08	0.62	1.22	0.14	0.29
D10	Skew	0.90	0.65	0.45	0.32	0.30	0.54	0.78	0.63	0.63
	Kurt	0.89	0.33	-0.49	-0.84	-1.06	0.01	0.62	-0.18	0.10
A11	Skew	0.78	0.75	0.67	0.84	0.81	0.64	0.85	0.63	0.63
	Kurt	0.44	0.54	-0.14	0.07	0.13	0.07	0.57	-0.01	0.01
G6	Skew	0.70	0.68	0.37	0.96	0.83	0.75	1.36	0.71	0.35
	Kurt	0.14	0.04	-0.83	0.36	-0.19	0.38	2.36	-0.22	-0.34
C8	Skew	0.59	0.50	0.39	0.71	0.80	0.78	0.69	0.88	0.67
	Kurt	-0.06	-0.08	-0.62	-0.08	0.19	0.48	0.18	0.62	-0.28
260%	Skew	0.99	0.73	0.72	0.55	0.59	1.21	0.69	1.16	0.52
	Kurt	1.56	0.45	-0.25	-0.13	-0.17	1.60	0.18	0.84	-0.09
ALL	**Skew**	**1.21**	**0.77**	**1.74**	**1.14**	**1.18**	**4.15**	**1.01**	**1.67**	**1.25**
	Kurt	**2.20**	**0.43**	**5.36**	**1.43**	**1.31**	**29.36**	**1.23**	**3.09**	**1.81**

Appendix E

Summaries of one-way ANOVAs on the effect of color on color uniformity with Tukey analysis.

One-way ANOVA: DE2000 versus Color-Inkjet

Source	DF	SS	MS	F	P
Color-IJ	10	316.232	31.623	1103.12	0.000
Error	50149	1437.617	0.029		
Total	50159	1753.849			

S = 0.1693 R-Sq = 18.03% R-Sq(adj) = 18.01%

Grouping Information Using Tukey Method

Color-IJ	N	Mean	Grouping
H3	4560	0.4582	A
B7	4560	0.4327	B
C4	4560	0.3941	C
C8	4560	0.3223	D
BLK	4560	0.3065	E
G6	4560	0.3019	E
A11	4560	0.2684	F
D2	4560	0.2599	F
D10	4560	0.2576	F
G9	4560	0.2442	G
F2	4560	0.1926	H

Means that do not share a letter are significantly different.

One-way ANOVA: DE2000 versus Color-PA Electrophotographic

Source	DF	SS	MS	F	P
Color-PA	10	1898.12	189.81	996.73	0.000
Error	50149	9550.13	0.19		
Total	50159	11448.25			

S = 0.4364 R-Sq = 16.58% R-Sq(adj) = 16.56%

Grouping Information Using Tukey Method

Color-PA	N	Mean	Grouping
B7	4560	1.1440	A
D10	4560	1.0138	B
BLK	4560	1.0061	B C
C4	4560	0.9836	C D
D2	4560	0.9732	D
F2	4560	0.8611	E
G6	4560	0.7374	F
H3	4560	0.7099	F G
G9	4560	0.6885	G
C8	4560	0.5792	H
A11	4560	0.5100	I

Means that do not share a letter are significantly different.

Appendix E (continued)

Summaries of one-way ANOVAs on the effect of color on color uniformity with Tukey analysis.

One-way ANOVA: DE2000 versus Color-PB Electrophotographic

Source	DF	SS	MS	F	P
Color-PB	10	14954.43	1495.44	1248.51	0.000
Error	50149	60067.71	1.20		
Total	50159	75022.14			

S = 1.094 R-Sq = 19.93% R-Sq(adj) = 19.92%

Grouping Information Using Tukey Method

Color-PB	N	Mean	Grouping
H3	4560	3.264	A
B7	4560	2.192	B
C4	4560	1.960	C
BLK	4560	1.898	C
D2	4560	1.770	D
G9	4560	1.759	D
D10	4560	1.615	E
G6	4560	1.593	E
C8	4560	1.339	F
A11	4560	1.239	G
F2	4560	1.217	G

Means that do not share a letter are significantly different.

One-way ANOVA: DE2000 versus Color-PCa Electrophotographic

Source	DF	SS	MS	F	P
Color-PCa	10	6378.84	637.88	698.38	0.000
Error	50149	45804.75	0.91		
Total	50159	52183.59			

S = 0.9557 R-Sq = 12.22% R-Sq(adj) = 12.21%

Grouping Information Using Tukey Method

Color-PCa	N	Mean	Grouping
B7	4560	2.1699	A
G9	4560	1.9917	B
C4	4560	1.7451	C
G6	4560	1.6731	D
D10	4560	1.6675	D
D2	4560	1.6554	D
F2	4560	1.2790	E
C8	4560	1.2574	E
BLK	4560	1.2548	E F
H3	4560	1.1918	F
A11	4560	0.9405	G

Means that do not share a letter are significantly different.

Appendix E (continued)

Summaries of one-way ANOVAs on the effect of color on color uniformity with Tukey analysis.

One-way ANOVA: DE2000 versus Color-PCb Electrophotographic

Source	DF	SS	MS	F	P
Color-PCb	10	6791.31	679.13	810.36	0.000
Error	50149	42027.73	0.84		
Total	50159	48819.04			

S = 0.9155 R-Sq = 13.91% R-Sq(adj) = 13.89%

Grouping Information Using Tukey Method

Color-PCb	N	Mean	Grouping
B7	4560	2.1549	A
G9	4560	1.7229	B
C4	4560	1.7153	B
D10	4560	1.6789	B C
D2	4560	1.6382	C
G6	4560	1.4732	D
F2	4560	1.1531	E
BLK	4560	1.1510	E
C8	4560	1.1069	E
H3	4560	1.0412	F
A11	4560	0.9014	G

Means that do not share a letter are significantly different.

One-way ANOVA: DE2000 versus Color-PD Electrophotographic

Source	DF	SS	MS	F	P
Color-PD	10	2278.28	227.83	342.68	0.000
Error	50149	33340.81	0.66		
Total	50159	35619.09			

S = 0.8154 R-Sq = 6.40% R-Sq(adj) = 6.38%

Grouping Information Using Tukey Method

Color-PD	N	Mean	Grouping
B7	4560	1.4985	A
G9	4560	1.2513	B
BLK	4560	1.2391	B
D10	4560	1.1441	C
G6	4560	1.0873	D
F2	4560	1.0091	E
H3	4560	0.9519	F
C8	4560	0.9213	F
C4	4560	0.9006	F
D2	4560	0.8291	G
A11	4560	0.7138	H

Means that do not share a letter are significantly different.

Appendix E (continued)

Summaries of one-way ANOVAs on the effect of color on color uniformity with Tukey analysis.

One-way ANOVA: DE2000 versus Color-PE Electrophotographic

Source	DF	SS	MS	F	P
Color-PE	10	925.19	92.52	400.77	0.000
Error	50149	11577.00	0.23		
Total	50159	12502.19			

S = 0.4805 R-Sq = 7.40% R-Sq(adj) = 7.38%

Grouping Information Using Tukey Method

Color-PE	N	Mean	Grouping
B7	4560	1.1304	A
C4	4560	0.9929	B
C8	4560	0.8958	C
A11	4560	0.8935	C
D2	4560	0.8922	C
G6	4560	0.8333	D
G9	4560	0.8195	D
F2	4560	0.8135	D
D10	4560	0.7507	E
BLK	4560	0.6807	F
H3	4560	0.6109	G

Means that do not share a letter are significantly different.

One-way ANOVA: DE2000 versus Color-PF Electrophotographic

Source	DF	SS	MS	F	P
Color-PF	10	22705.78	2270.58	1566.18	0.000
Error	50149	72703.92	1.45		
Total	50159	95409.71			

S = 1.204 R-Sq = 23.80% R-Sq(adj) = 23.78%

Grouping Information Using Tukey Method

Color-PF	N	Mean	Grouping
C4	4560	2.833	A
D2	4560	2.584	B
B7	4560	2.262	C
H3	4560	2.112	D
F2	4560	1.677	E
D10	4560	1.656	E
G6	4560	1.424	F
C8	4560	1.050	G
BLK	4560	0.998	G
A11	4560	0.903	H
G9	4560	0.797	I

Means that do not share a letter are significantly different.

Appendix E (continued)

Summaries of one-way ANOVAs on the effect of color on color uniformity with Tukey analysis.

One-way ANOVA: DE2000 versus Color-PG Electrophotographic

Source	DF	SS	MS	F	P
Color-PG	10	4759.74	475.97	1121.06	0.000
Error	50149	21292.06	0.42		
Total	50159	26051.80			

S = 0.6516 R-Sq = 18.27% R-Sq(adj) = 18.25%

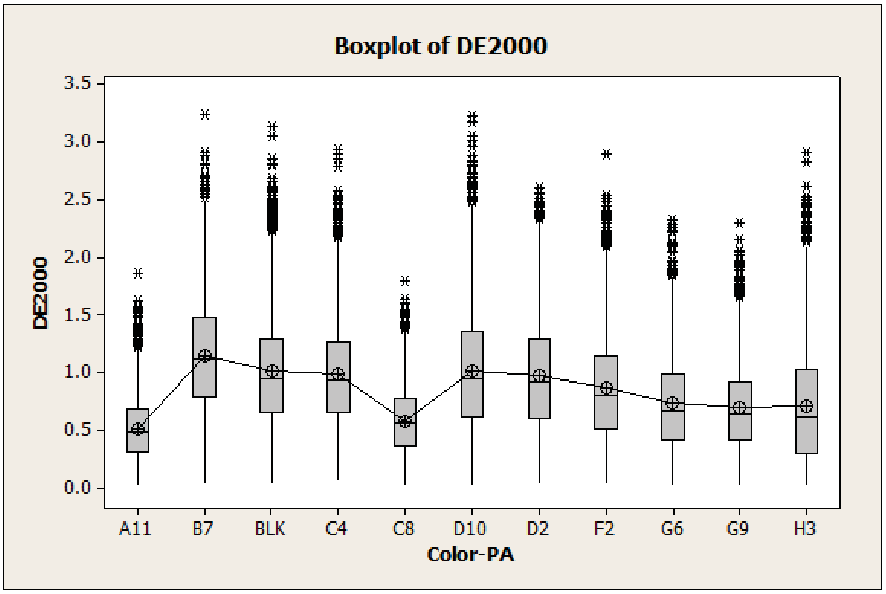
Grouping Information Using Tukey Method

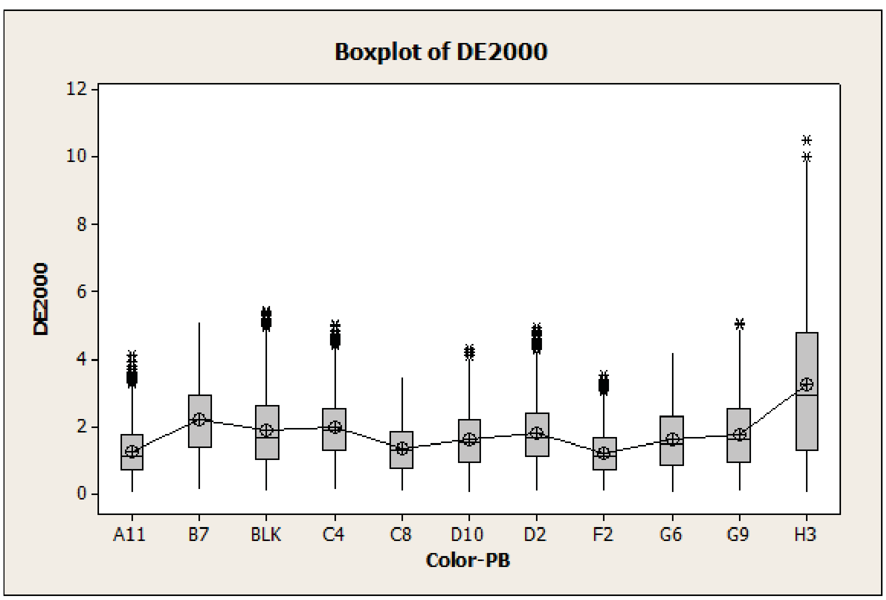
Color-PG	N	Mean	Grouping
C8	4560	1.6009	A
C4	4560	1.5699	A
B7	4560	1.5608	A
H3	4560	1.1272	B
A11	4560	1.1176	B
G6	4560	1.0374	C
BLK	4560	1.0152	C
G9	4560	0.9401	D
D2	4560	0.8203	E
F2	4560	0.7581	F
D10	4560	0.7392	F

Means that do not share a letter are significantly different.

Appendix F

Boxplots for each press/color combination.





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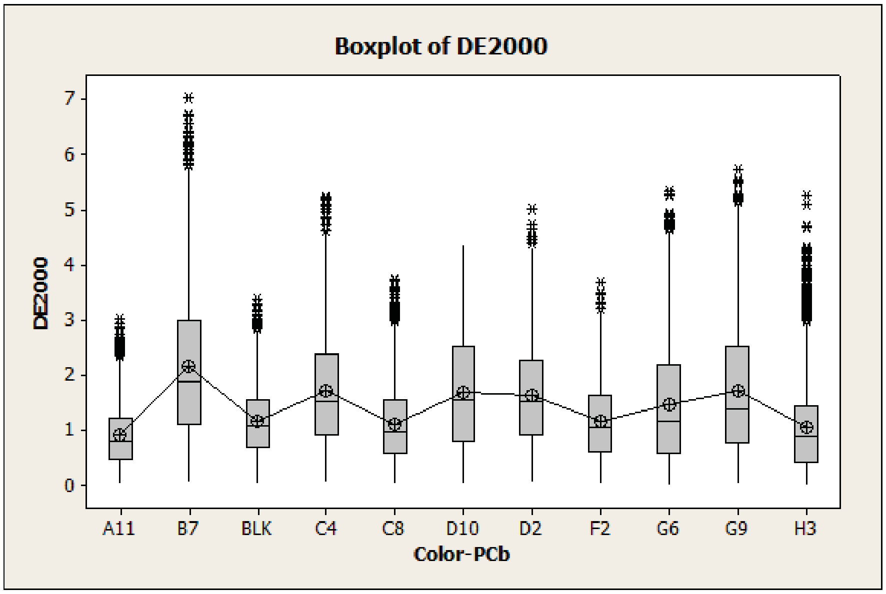

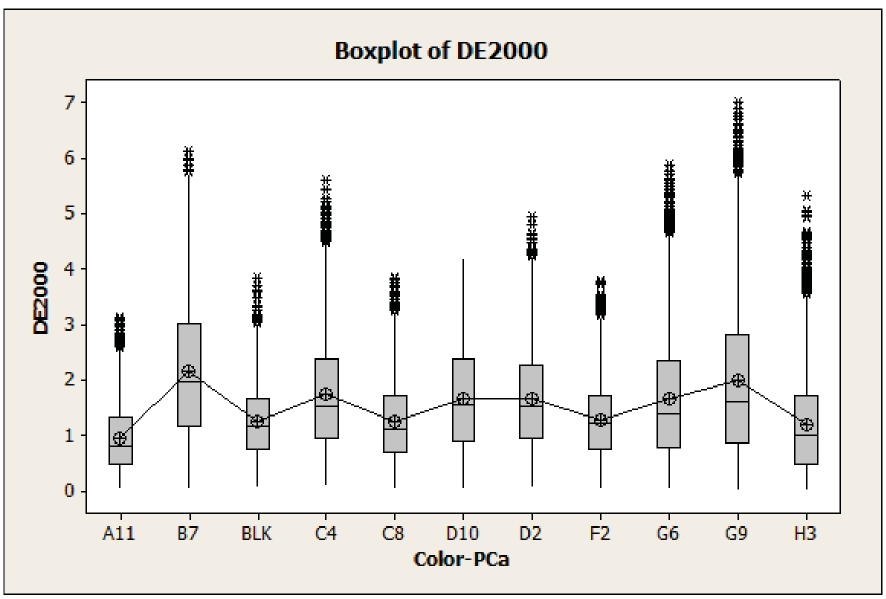

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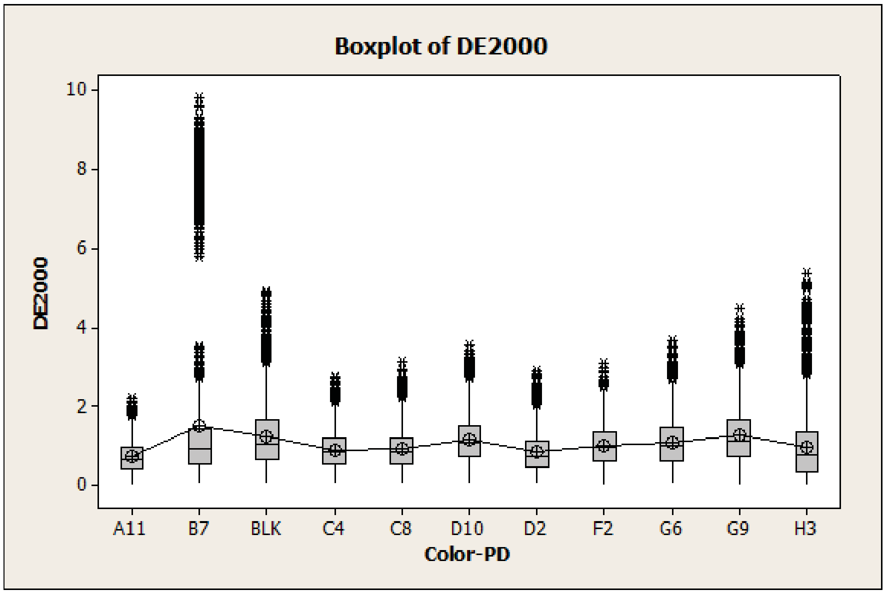
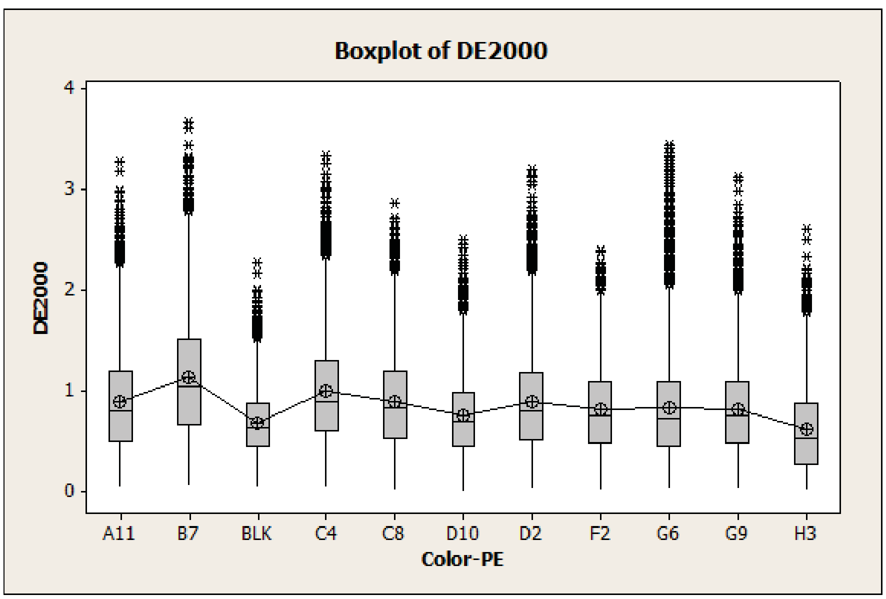
Boxplots for each press/color combination.





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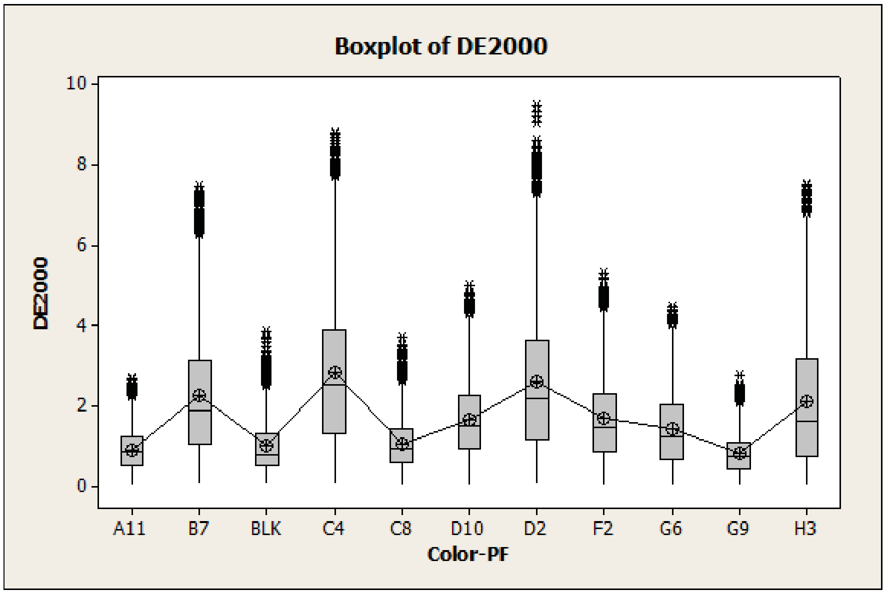
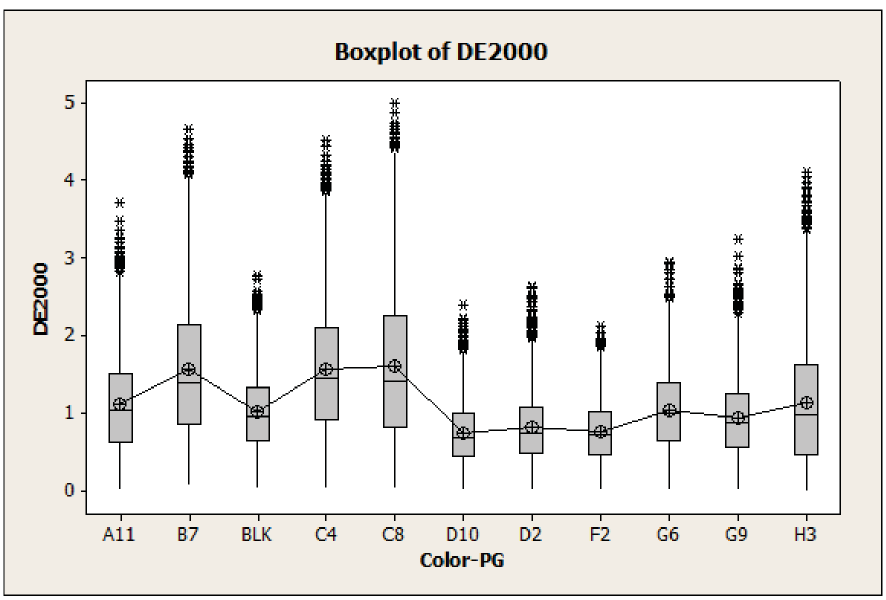
Boxplots for each press/color combination.





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Boxplots for each press/color combination.