2011

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A Research Monograph of the Printing Industry Center at RIT

No. PICRM-2011-08

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R·I·T Printing Industry Center
An Alfred P. Sloan Foundation Center

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Rochester, NY
March 2011

PICRM-2011-08

With Thanks

The research agenda of the Printing Industry Center at RIT and the publication of research findings are supported by the following organizations:

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Executive Summary

The PSA database consists of 35 press sheets submitted for ISO 12647-2 printing conformance assessment during 2010. This report is divided into two sections, (1) measurement variation, and (2) printing variation and conformance. Each section is then organized based on several topics studied. Objectives are stated for each topic, followed by procedures used, results, and discussions of major findings.

Variation exists in the measurement process—including inter-instrument agreement, spatial variation, sheet-to-sheet variation, and precision—all of which were studied. In terms of inter-instrument agreement, only two X-Rite i1 iSis instruments were used at RIT, and hence a very good inter-instrument agreement was found: an uncertainty of about 0.4 ΔE. In terms of spatial variation, the result shows that, on average, there is an uncertainty of about 0.9 ΔE, assessed by a single instrument. In terms of sheet-to-sheet variation, there is an average uncertainty of about 0.9 ΔE. In terms of instrument precision, the performance of the X-Rite i1 iSis auto-scanning spectrophotometer is negligible (0.1 ΔE).

For printing variation and conformance, the following parameters were investigated: (1) substrate color, (2) printed solids, TVI, and mid-tone spreads, (3) tone reproduction limits, and (4) near-neutral variation. In terms of substrate color variation and conformance, these mainly consisted of shifts to bluer color. In terms of printed solids, KCMY solids conformances were 90%, 80%, 90%, and 55% respectively when judging by color, and the conformance was 34% when judging by job. Many yellow solids are less chromatic than the ISO aim due to bluish paper. In terms of TVI, the conformance is about 65% for 50% tone value when judging by color. When judging by job, 20% of files conform to the ISO 12647-2 criteria at 50% tone value. Low conformance is due to the fact that most U.S. printers calibrate their presses using near-neutral methods. In terms of mid-tone spread, 60% of files conform to the ISO 12647-2 criterion.

There is no clear assessment method for tone reproduction limits. Thus, an innovative method was used by utilizing ΔEs between the reference points (0% and 100%) and their neighbors at either end of the tonal scale. The straight-line between (0%, 0 ΔE) and (10%, 6 ΔE) was used to flag non-conforming jobs at the highlight region of CMYK; similarly, a straight-line between (100%, 0 ΔE) and (90%, 3 ΔE) was used to flag non-conforming jobs at the shadow region of CMYK for further visual examination. As a result, about one-third of the database required further visual judgment under region-wise judgment.

In terms of near-neutral variation, measured outcomes of near-neutral triplets relative to substrate-based grey ramp (SBGR) were analyzed graphically. Grey reproduction of these near-neutral triplets, in terms of ΔC_h [1] and ΔL^*, were computed between substrate-corrected colorimetric aims (SCCA) and measurement. In turn, ΔC_h and

1- Formerly ΔF^*.

ΔL^* were compared with the tolerances for conformance decision. Grey reproduction conformances were 57% | 86% (ΔC_h | ΔL^*), 63% | 57%, 71% | 71%, and 23% for quarter-tone, mid-tone, three-quarter-tone, and job-wise judgment, respectively.

In conclusion, this research provides an analysis of an unfiltered database regarding printing variation and its conformance to ISO 12647-2. It also explored two innovative assessment methods: tone reproduction limits and grey reproduction.

Introduction

RIT is developing a Printing Standards Audit (PSA) program that certifies printing companies who have demonstrated their abilities to conform to ISO printing requirements. RIT is also contributing to the development of printing standards at the national and international level. A reason that RIT is engaged in these activities is because of its expertise and curriculum in print media technology. Understanding variation in printed products through database analysis and utilizing statistics to make decisions in tolerance settings and in printing conformance are central to the mission of the PSA program.

The objective of this report was to analyze the variance of the PSA database. The source of the PSA database was a survey of 35 printing companies (N=35 jobs, with two samples per job). Each printing company submitted five sample sheets. Two of these sheets were measured by two instruments twice. Therefore, there were a total of 8 sets of measurements for each printing company (2 sheets x 2 instruments x 2 times). The printing target was IT8.7/4, which includes 1,617 patches. The measurement instruments were two X-Rite i1 iSis with M0 mode and white backing.

The analysis was focused on data variance as supplied in the files of (1) measurement summary, and (2) data set analysis. In order to summarize measurement variation, this project reports deviation conformance of the database to ISO 12647-2. This project excludes the variation conformance analysis because no production samples were included in the database.

Approaches to Data Analysis

When a printer sent in his or her press sheets for printing conformance check-up during the PSA survey in 2010, two IT8.7/4 targets, each consisting of 1,617 color patches, were measured. There were 35 submissions and thus a total of 113,190 measurement values.

Data is not information until it has been analyzed, presented in a meaningful manner such as figures and tables, and explained in an easy-to-understand way. If outliers are detected, they are removed from further data analysis. Matlab was used to extract data from Excel sheets and to perform computation and graphing throughout the project.

The analysis can be divided into two sections: measurement variation and printing variation. In either case, the distribution of the data relative to a specific parameter, e.g., inter-instrument agreement, is shown. The central tendency and the spread of the data are discussed.

Color difference or ΔE distribution is often not Gaussian in shape. A cumulative relative frequency distribution (known as the CRF curve) is used to describe the color difference as a function of probability. The CRF curve also allows the use of its 90th percentile feature to set the threshold to flag values in the top 10th percentile.

This document is organized based on several topics studied. Objectives are stated for each topic followed by the procedures used, results, and discussions of major findings. When appropriate, results from this study were compared with results analyzed from the PSO database (Fogra, 2010).

Measurement Variation

Variation exists in the printing process as well as in the measurement process. Therefore, measurement-related variations were examined as the first part of the PSA Survey press sheet check-up. These include inter-instrument agreement, spatial variation, sheet-to-sheet variation, and precision.

Inter-Instrument Agreement

Objective

To determine the inter-instrument agreement between two instruments used in creating measurements for the PSA database.

Input

The average, 90th percentile, and maximum ΔE of inter-instrument validation data for each job. These data were calculated based on all 1,617 patches of the target. There are 35 jobs, and, in each job, there are two sets of input—Sheet 1 and Sheet 2, respectively—measured by two i1 iSis spectrophotometers.

Procedure

1. Average data of two sheets as one set for each job.
2. Plot a combined histogram of average ΔEs between the two instruments.
3. Plot the CRF of ΔEs of all 35 jobs.
4. Calculate the mean, standard deviation, and standard error.

Results

The histogram of average ΔEs for all 35 jobs is shown in Figure 1. The mean is 0.4 ΔE, a relatively small difference because the two instruments compared are of the same model.

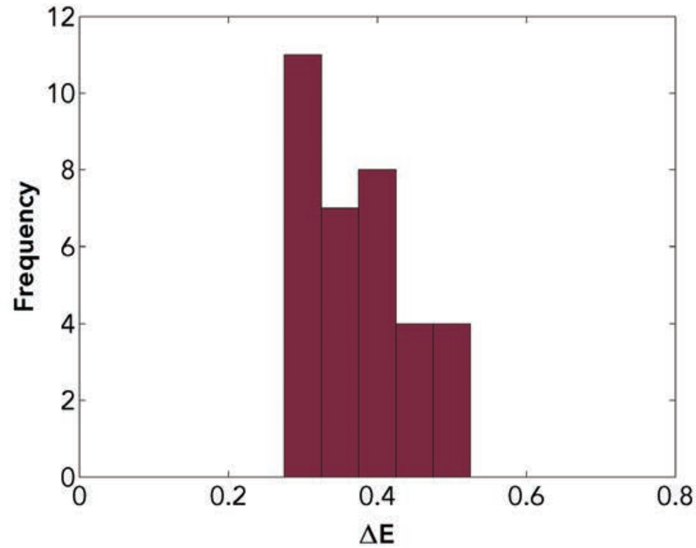


Figure 1. Histogram for the mean value of inter-instrument agreement

The CRF plots are shown in Figure 2. Qualitatively, the span of the CRF curves is an indication of variation due to inter-instrument agreement. One outlier with grey curve was removed in further data analysis. Quantitatively, the mean of the 50th percentile is 0.4 ΔE, and the mean of the 90th percentile is 0.6 ΔE.

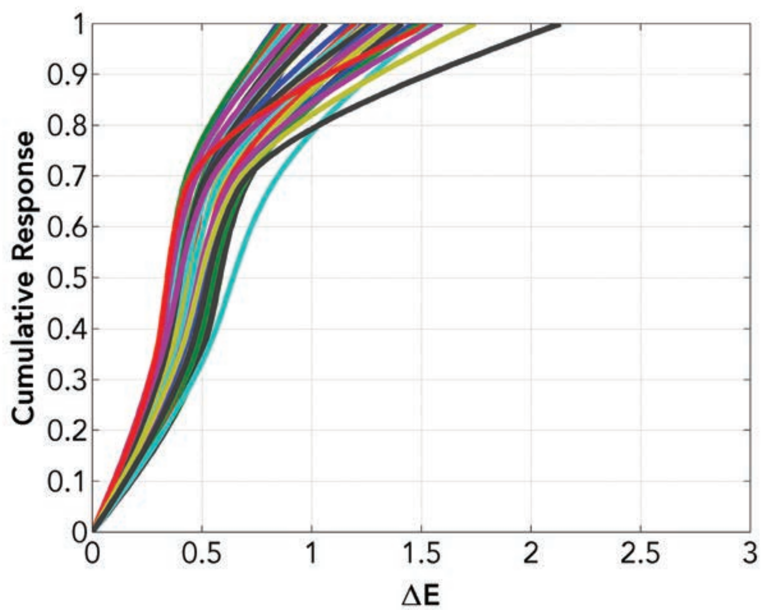


Figure 2. CRF plots for inter-instrument agreement

The means of the average distribution (0.4 ΔE), 90th percentile distribution (0.6 ΔE), and maximum distribution (1.2 ΔE) form thresholds that serve as quality control points for inter-instrument agreement during the measurement validation process (see Table 1, n=34).

Table 1. Descriptive statistics of inter-instrument agreement

Distribution Type	Mean	SD	SE
Distribution of Average	0.4	0.06	0.01
Distribution of 90th Percentile	0.6	0.10	0.02
Distribution of Maximum	1.2	0.24	0.04

Discussion

Only RIT instruments were used, and hence a very good inter-instrument agreement is expected. The result shows that, on average, there is an uncertainty of about 0.4 ΔE between two instruments of the same brand and make. The uncertainty should be larger between any two instruments of arbitrary brands. Therefore, for printing certification, inter-instrument agreement should be taken into consideration when certifying the conformance. When printers use the same measurement instrument as certification bodies, the inter-instrument agreement is minimized. However, even when the same instrument is used, uncertainty still exists (0.4 ΔE in this survey).

With respect to inter-instrument agreement, there are two differences between the PSA database and the PSO database. First, PSA uses two instruments of the same brand while PSO uses three different brands. Second, PSA measures all of the 1,617 color patches in the IT8.7/4 target while PSO only measures four CMYK solids. The result of the comparison, as shown in Table 2, indicates that, on average, the inter-instrument difference between the same brands is 0.4 ΔE while the difference between different brands is 1.4 ΔE.

Table 2. Inter-instrument agreement comparison of PSA and PSO databases

Category	PSA Database	PSO Database
Measurement Instruments	Two i1 iSis	GretagMacbeth SpectroEye, Techkon SpectroDens, X-Rite 530
Number of Jobs	35	88
Number of Patches	1617 (IT8.7/4)	4 (Solids)
Inter-Instrument Agreement	0.4 ΔE	1.4 ΔE

There are two implications regarding the above findings: (a) inter-instrument agreement may be a concern in printing certification activities (i.e., the potential poor agreement between the instruments used by the printer and the certification body); and (b) solutions that lead to better inter-instrument agreement, such as XRGA (X-Rite, 2010) and NetProfiler (X-Rite, 2006), are needed in order to enable printing standardization activities.

Spatial Variation

Objective

To determine the spatial or within-sheet variation of all 35 jobs.

Input

There are 29 pairs of repeating patches (58 patches) in the IT8.7/4 target. Spatial variation of the printing device is estimated by the ΔEs among these 29 pairs. The input data includes the average, 90^{th} percentile, and maximum ΔE of spatial variation data for each job. There are 35 jobs with 8 sets of input in each job.

Procedure

1. Average 8 sets of data (2 instruments x 2 sheets x 2 measurements) as one set for each job.
2. Plot a histogram of average ΔEs for all samples.
3. Plot the CRF of ΔEs for all 35 jobs.
4. Calculate the mean, standard deviation, and standard error.

Results

The histogram of average ΔEs for 35 jobs is shown in Figure 3. The mean value is 0.9 ΔE.

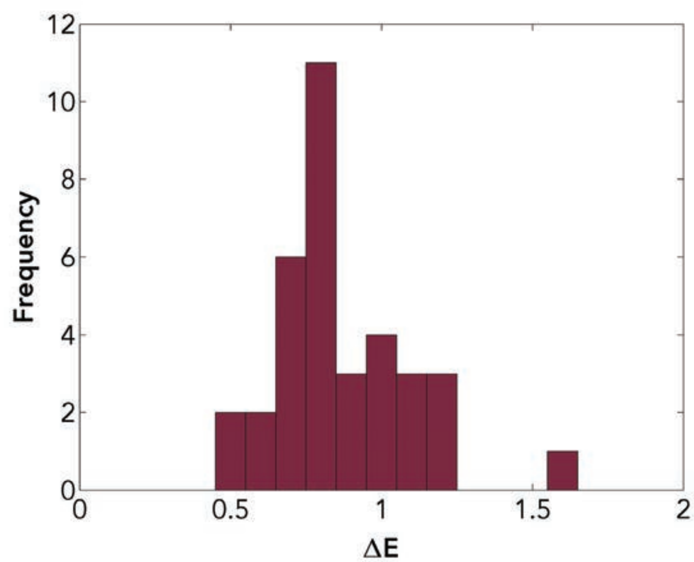


Figure 3. Histogram for the mean value of spatial variation

The CRF plots of 35 jobs are shown in Figure 4. Qualitatively, the span of these CRF curves is larger than the inter-instrument agreement by visual inspection. Quantitatively, the mean of the 50th percentile is 0.9 ΔE, and the mean of the 90th percentile is 1.8 ΔE.

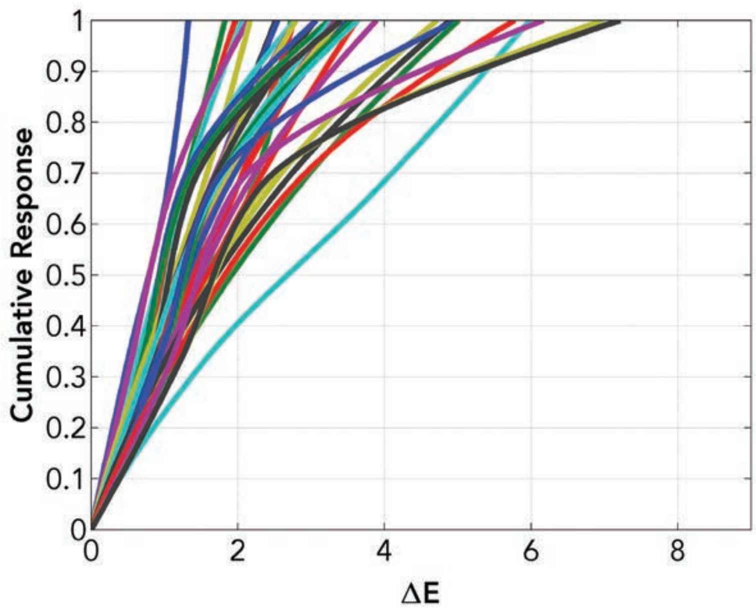


Figure 4. CRF plots for spatial variation

The means of the average distribution (0.9 ΔE), 90th percentile distribution (1.8 ΔE), and maximum distribution (3.6 ΔE) form thresholds that serve as quality control points for spatial variation during the measurement validation process (see Table 3, n=35).

Table 3. Descriptive statistics of spatial variation

Distribution Type	Mean	SD	SE
Distribution of Average	0.9	0.22	0.04
Distribution of 90th Percentile	1.8	0.58	0.10
Distribution of Maximum	3.6	1.46	0.25

Discussion

The results show that, on average, there is an uncertainty of about 0.9 ΔE due to spatial variation as assessed by a single instrument. The mean of the 90th percentile distribution, 1.8 ΔE, is recommended as the threshold for detecting very large spatial variation (i.e., a decision is made that there is likely a real difference in two input values due to within-sheet variation if their measurements differ more than 1.8 ΔE). The best and worst four jobs in terms of mean value were investigated. There is no causal relationship between the press technology and the spatial variation.

With respect to spatial variation, there is a difference between the PSA database and the PSO database. PSA uses 29 pairs of repeating patches in the IT8.7/4 target (A4), and PSO uses four solid patches in three different locations from the same press sheet (A3). The result of the comparison, as shown in Table 4, indicates that, on average, the spatial variation at A4 size (0.9 ΔE) is less than the spatial variation of 1.4 ΔE at A3 size.

Table 4. Spatial variation comparison of PSA and PSO databases

Category	PSA Database	PSO Database
Measurement Locations	29 pairs of repeating patches in IT8.7/4 on an A4 size paper	Left-bottom, center-top, & right-bottom on an A3 size paper
Number of Jobs	35	88
Number of Patches	29 pairs	4 (Solids)
Spatial Variation	0.9	1.4

Sheet-to-Sheet Variation

Objective

To evaluate sheet-to-sheet variation whereby sheets are sampled at color OK.

Input

The average, 90th percentile, and maximum ΔE of sheet-to-sheet variation data for each job.

Procedure

1. Plot the histogram.
2. Plot the CRF of ΔEs of all 35 jobs.
3. Calculate the mean, standard deviation, and standard error.

Results

The histogram of average ΔEs for 35 jobs is shown in Figure 5. The shape of the distribution is not normal. The mean is 0.9 ΔE.

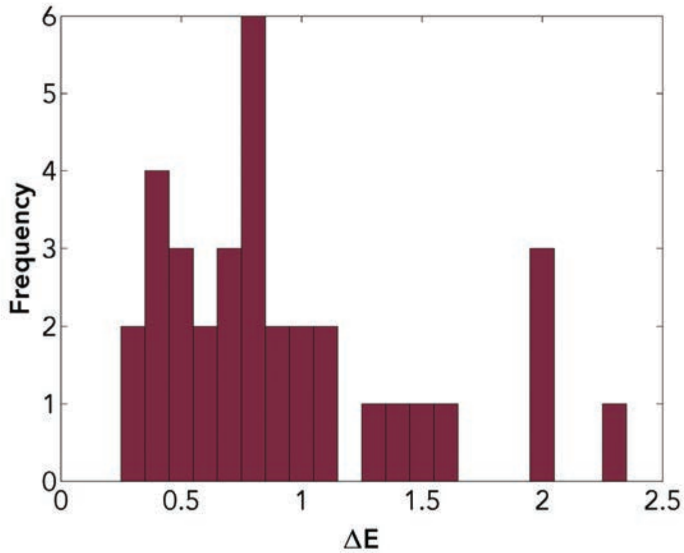


Figure 5. Histogram for the mean value of sheet-to-sheet variation

The CRF plots of all 35 jobs are shown in Figure 6. Qualitatively, the span of the CRF curves is similar to the spatial variation CRF curves by visual inspection. Quantitatively, the mean of the 50th percentile is 0.9 ΔE, and the mean of the 90th percentile is 1.7 ΔE. The CRF curve at far right with 12 ΔE at its 90th percentile is deemed an outlier.

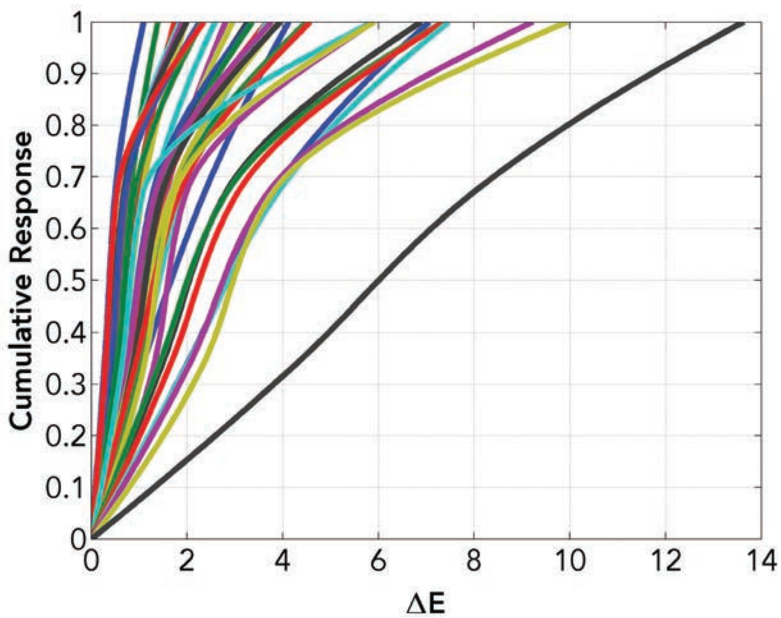


Figure 6. CRF plot for sheet-to-sheet variation

The means of the average distribution (0.9 ΔE), 90th percentile distribution (1.7 ΔE), and maximum distribution (4.2 ΔE) form thresholds that serve as quality control points for sheet-to-sheet variation during the measurement validation process (see Table 5, n=34).

Table 5. Descriptive statistics of sheet-to-sheet variation

Distribution Type	Mean	SD	SE
Distribution of Average	0.9	0.53	0.09
Distribution of 90th Percentile	1.7	0.99	0.17
Distribution of Maximum	4.2	2.32	0.40

Discussion

On average, there is an uncertainty of about 0.9 ΔE due to sheet-to-sheet variation. The mean of the 90th percentile distribution, 1.7 ΔE, is recommended as the threshold for detecting extreme sheet-to-sheet variation. With respect to sheet-to-sheet variation, there is a difference between the PSA database and the PSO database. PSA uses two sheets and the IT8.7/4 target while PSO uses three sheets and CMYK solids. The result of the comparison indicates that color difference correlates with the number of color patches analyzed as shown in Table 6. There tends to be more color variation (0.9 ΔE) when a large number of color patches are analyzed and less color variation (0.4 ΔE) when only four solids are analyzed.

Table 6. Sheet-to-sheet variation comparison of PSA and PSO databases

Category	PSA Database	PSO Database
Measurement Locations	2 sheets	3 sheets
Number of Jobs	35	88
Number of Patches	1617 (IT8.7/4)	4 (Solids)
Sheet-to-sheet Variation	0.9	0.4

This is a special case of the sheet-to-sheet variation because the time difference between the two samples was extremely short. A much larger color difference is likely to occur if the two sheets are sampled at longer time intervals, such as the difference between the first and last sheet of a production run.

Instrument Precision

Objective

To examine the instrument precision or repeatability of the same instrument measuring the same target at different times.

Input

The average, 90th percentile, and maximum ΔE of instrument precision data for each job.

Procedure

1. Average the 4 sets of data as one set for each job.
2. Plot the histogram.
3. Plot the CRF of ΔEs of all 35 jobs.
4. Calculate the mean, standard deviation, and standard error.

Results

The histogram of ΔEs at average for 35 jobs is shown in Figure 7. The mean value is 0.1 ΔE.

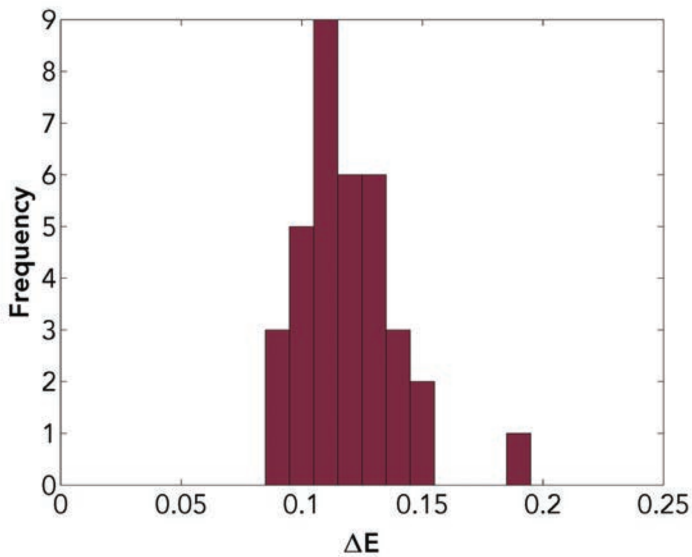


Figure 7. Histogram for the mean value of instrument precision

The CRF plots of all 35 jobs are shown in Figure 8. Quantitatively, the mean of the 50^{th} percentile is 0.1 ΔE, and the mean of the 90^{th} percentile is 0.2 ΔE. The example with the grey line is deemed to be an outlier.

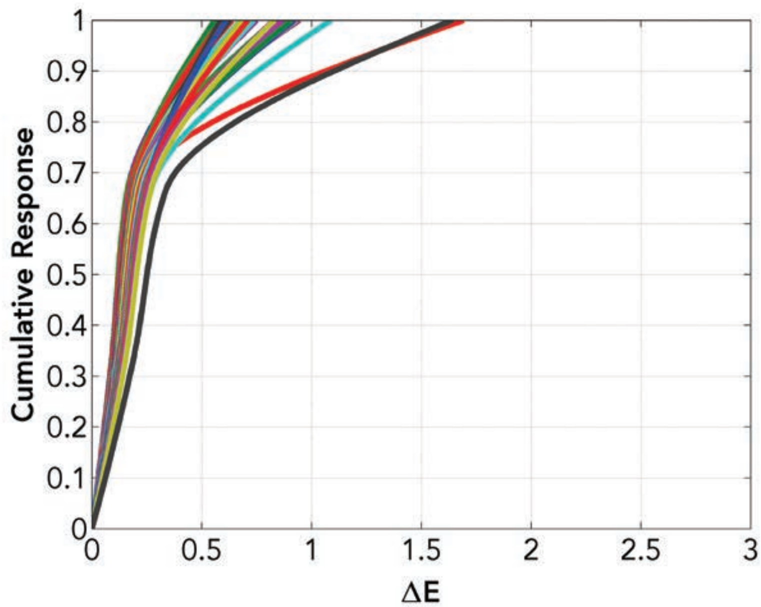


Figure 8. CRF plot for instrument precision

The means of the average distribution (0.1 ΔE), 90th percentile distribution (0.2 ΔE), and maximum distribution (0.8 ΔE) form thresholds that serve as quality control points for instrument precision during the measurement validation process (see Table 7, n=34).

Table 7. Descriptive statistics of instrument precision

Distribution Type	Mean	SD	SE
Distribution of Average	0.1	0.02	0.00
Distribution of 90th Percentile	0.2	0.04	0.01
Distribution of Maximum	0.8	0.25	0.04

Discussion

X-Rite i1 iSis is an auto-scanning spectrophotometer. There is no human factor in the measurement process, which results in good instrument precision. The repeatability of a hand-held instrument is likely to have a larger color difference than an auto-scanning spectrophotometer would.

Printing Variation and Conformance

When a printer submits his or her press sheets for a free printing conformance check-up, he receives a check-up report card with the following parameters described: substrate color conformance and deviation of OK print for printed solids, TVI, and mid-tone spread. He may wonder how his printing fares with the rest of the submissions. However, this part of the report only provides a statistical summary of all of the printing parameters mentioned without identifying any individual. Findings from the PSA Survey database may be discussed, when appropriate, in relation to findings from the PSO database.

Substrate Color Variation and Conformance

Objective

Examine the variation of substrate color and conformance to the ISO 12647-2 specification.

Input

The CIELAB values of substrate color of all 35 jobs.

Procedure

1. Plot the a^*b^* coordinates and the ISO conformances.

Results

The variation of substrate colors is shown in Figure 9. There is a larger variation in b^* values than in a^* values.

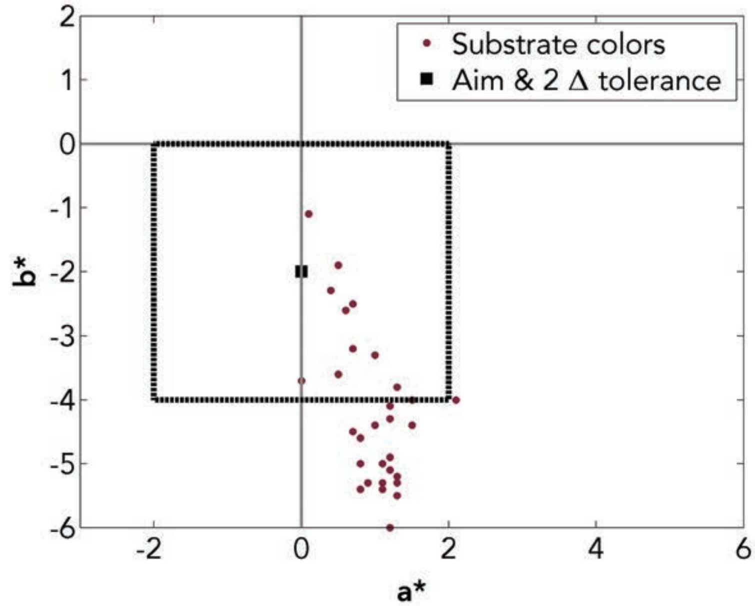


Figure 9. Variation of 35 substrate colors

Thirty-one percent of the files (11/35) conform to ISO 12647-2 criteria. Excessive b^* values were the major cause of non-conformance.

Discussion

The substrate colors were mainly shifted to bluer colors as expected. The variation of substrate colors for the PSO database (white backing) is shown in Figure 10 (triangles) along with the PSA substrate colors (dots). By visual inspection, the PSO database trend is similar to that of the PSA database. In terms of conformance, 57% of the files (8/14) in the PSO database conform to ISO criteria.

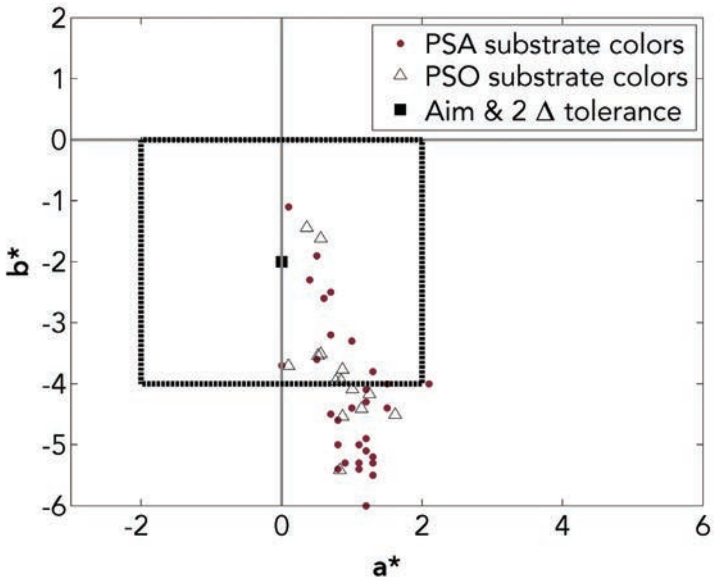


Figure 10. Variation of 14 substrate colors of the PSO database plotted with the 35 PSA data

Deviation of OK Print—Printed Solids

Objective

Examine the deviation of printed solids between OK print and published aims by color and by job.

Input

The color difference and hue difference values of 4 printed solids of all 35 jobs.

Procedure

1. Plot the color difference and hue difference values of each color for all 35 jobs as CRF, which indicate the conformance by color.

2. Evaluate the conformance by job.

Results

The CRFs of printed solids for all 35 jobs are shown in Figure 11. The conformance of printed solids is determined by the tolerance of 5 ΔE. By color, black and magenta solid conformances are at 90% in terms of ΔE. This is followed by cyan solid conformance at 80%. The percentage of yellow solid conformance is at 55%.

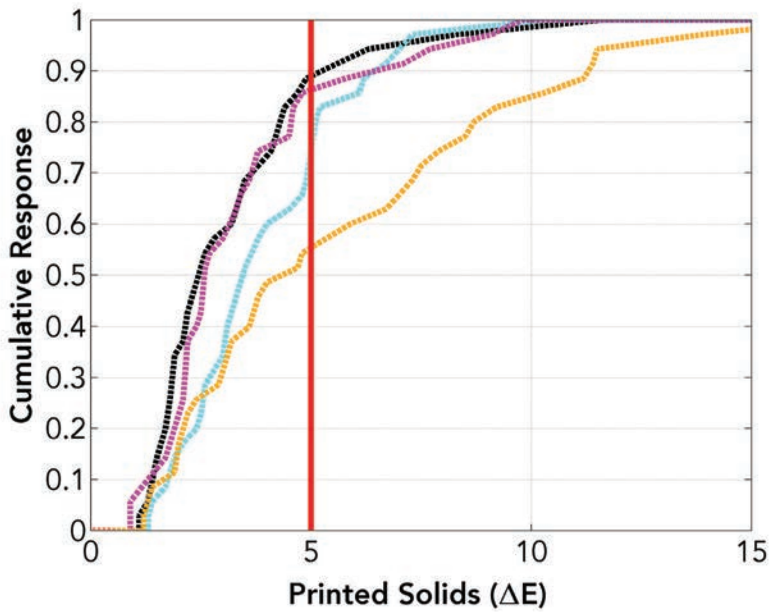


Figure 11. The CRF of printed solids ΔE [2]

The CRFs of printed solids ΔH for all 35 jobs are shown in Figure 12. In terms of ΔH, the conformance of printed solids is determined by the tolerance of 2.5. Cyan and yellow solid conformances, by color, are at 90%, followed by magenta solid conformance at 65%.

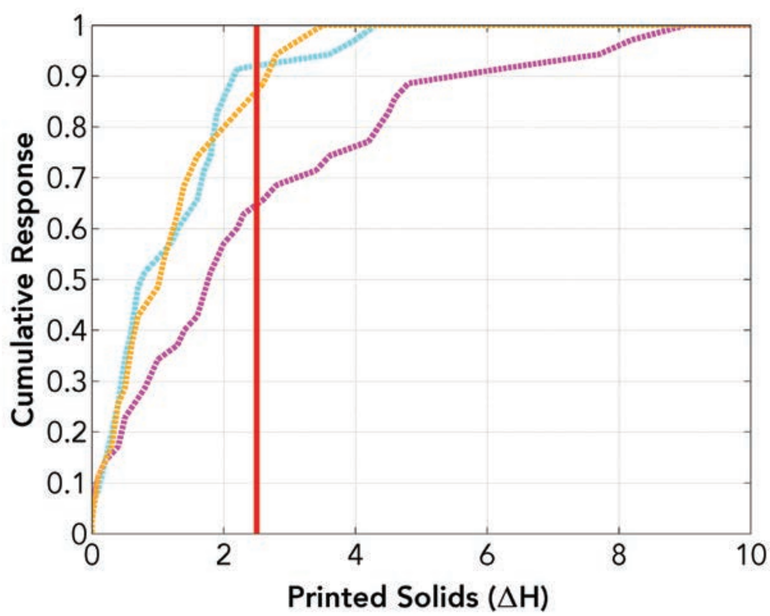


Figure 12. The CRF of printed solids ΔH [3]

By job, the conformance is only assigned as OK when all channels conform to the ISO 12647-2 criteria. Table 8 shows the job-wise conformance outcome. 34% of the files

2,3 - The red line is the ISO criterion.

(12/35) conform to the ISO criteria. In terms of only ΔE with no ΔH, 43% of the files (15/35) conform to the ISO criteria by job.

Table 8. Job-wise conformance by printed solids' color and hue differences

Job #	Tol.	ΔE_K	ΔE_C	ΔE_M	ΔE_Y	ΔH_C	ΔH_M	ΔH_Y	OK?
		5	5	5	5	2.5	2.5	2.5	
1	Δ	2.2	5.0	4.8	1.4	0.1	4.6	1.0	N
2	Δ	1.5	2.5	1.7	2.2	1.2	0.5	1.6	Y
3	Δ	1.3	1.7	3.4	11.5	0.6	2.6	1.5	N
4	Δ	11.6	6.1	2.2	3.2	1.9	1.8	1.1	N
5	Δ	2.1	3.5	1.8	5.9	0.7	0.1	0.7	N
6	Δ	4.4	1.3	2.1	2.9	0.8	1.3	2.0	Y
7	Δ	4.1	1.4	3.0	11.4	0.5	2.8	2.6	N
8	Δ	2.5	2.6	2.4	13.9	0.0	2.0	2.8	N
9	Δ	1.9	3.8	1.7	7.3	0.0	1.4	0.7	N
10	Δ	2.3	3.2	0.9	2.0	0.4	0.0	0.1	Y
11	Δ	2.4	4.9	4.6	1.4	0.2	4.5	1.1	N
12	Δ	1.8	3.3	0.9	1.9	0.3	0.1	0.0	Y
13	Δ	1.7	2.4	4.6	7.9	0.7	4.5	2.4	N
14	Δ	1.1	3.0	1.9	2.4	1.6	1.6	1.3	Y
15	Δ	4.1	6.7	9.1	9.2	0.5	8.2	3.5	N
16	Δ	1.5	2.1	2.6	8.7	1.8	0.5	0.3	N
17	Δ	4.7	1.9	3.3	2.2	1.7	1.0	1.0	Y
18	Δ	1.5	3.8	7.7	7.3	3.6	7.7	3.5	N
19	Δ	1.9	7.3	2.5	11.2	1.3	1.0	0.6	N
20	Δ	6.3	10.3	2.6	17.0	0.4	0.2	0.6	N
21	Δ	2.8	7.0	7.1	4.8	2.2	6.2	2.7	N
22	Δ	5.6	6.2	3.6	4.7	1.7	3.6	1.4	N
23	Δ	3.5	4.0	1.7	3.0	2.0	0.8	1.3	Y
24	Δ	1.8	2.6	2.2	3.7	1.6	1.8	0.1	Y
25	Δ	1.6	5.0	3.7	7.5	4.0	0.8	1.3	N
26	Δ	4.2	3.5	2.0	3.6	0.6	1.9	0.6	Y
27	Δ	2.2	5.1	5.8	6.7	4.3	4.8	1.4	N
28	Δ	1.9	3.0	4.5	1.2	2.2	4.2	0.5	N
29	Δ	3.3	3.1	2.7	3.8	0.5	0.4	1.8	Y
30	Δ	2.6	1.9	2.6	2.0	0.3	2.2	0.4	Y
31	Δ	3.4	5.2	3.3	5.9	1.2	2.3	0.4	N
32	Δ	3.2	4.8	9.8	4.0	1.9	9.0	0.1	N
33	Δ	4.9	4.5	2.2	3.2	0.7	1.8	2.2	Y
34	Δ	8.3	5.1	3.8	8.5	1.9	3.4	0.4	N
35	Δ	4.4	3.1	2.2	10.3	0.2	0.0	0.3	N

Discussion

When inspecting the data from color-wise analyses, yellow solids show low conformance while magenta hue differences show low conformance. When inspecting the data from job-wise analyses, there is no strong correlation between solid non-conformance and hue difference non-conformance.

Yellow has the lowest solid conformance to ISO 12647-2. Figure 13 shows the variation of yellow solids in the chroma direction relative to the ISO yellow aim point (black square). Many yellow solids are less chromatic than the ISO aim, which is due to the bluish paper used.

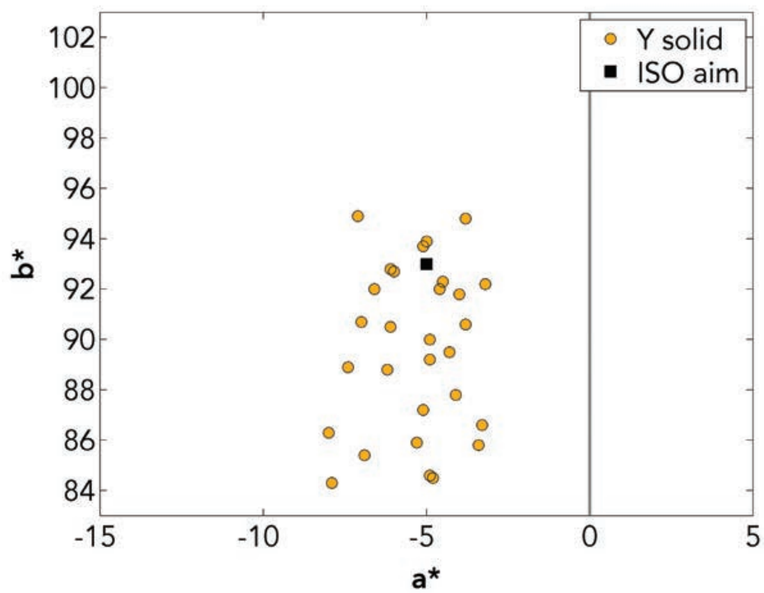


Figure 13. Variation of yellow solids compared to the ISO aim

Magenta has the lowest ΔH conformance to ISO 12647-2. Figure 14 shows the variation of magenta solids along with the ISO magenta aim point. The variation is mainly due to hue shifts caused by the use of bluish paper.

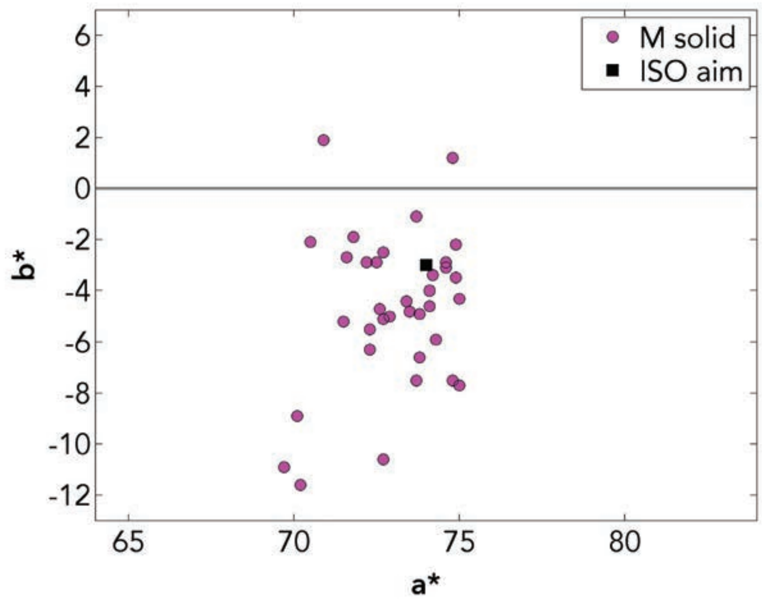


Figure 14. Variation of magenta solids compared to the ISO aim

Deviation of OK Print—TVI

Objective

Examine the distribution of deviation of TVI between OK print and published aims by color and by job.

Input

The TVI values of CMYK of 35 jobs at 50% and 80% tone values.

Procedure

1. Plot the TVI values of each color for 35 jobs as CRF, which indicates the conformance by color.
2. Evaluate the conformance by job.

Results

The CRFs of TVI values for 35 jobs are shown in Figures 15 and 16. The TVI conformance is determined by the tolerance of 4 at 50% tone value and 2.5 at 80% tone value. By color, the conformances of TVI are about 65% and 75% for tone values 50% and 80%, respectively. Because of the higher magnitude at 50%, it is expected that TVI at 50% is more sensitive to variation than TVI at 80%, which causes a lower conformance at the 50% tone value (even though it has a higher tolerance).

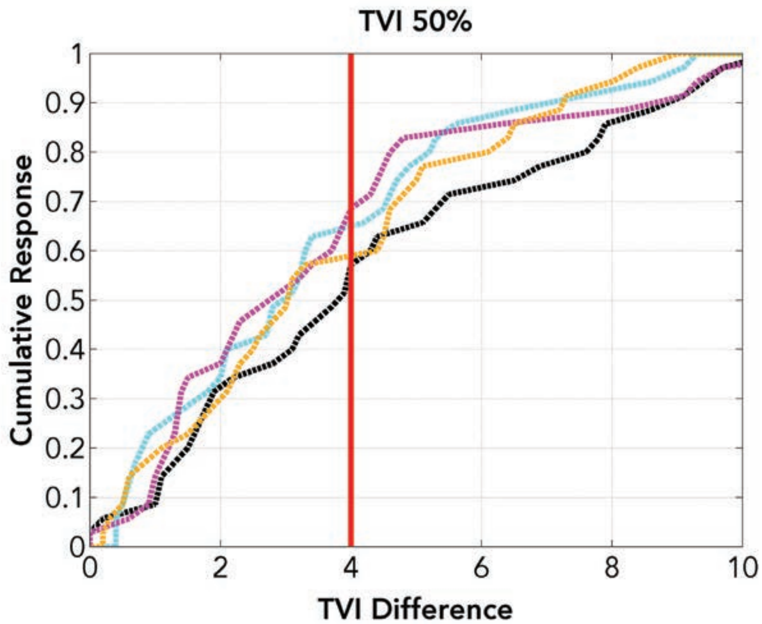


Figure 15. CRF of TVI at 50% tone value[4]

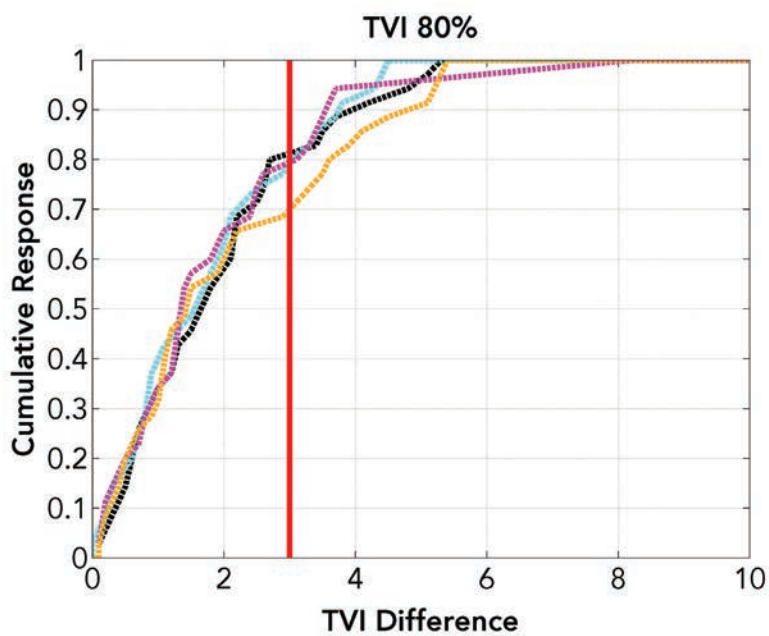


Figure 16. CRF of TVI at 80% tone value[5]

Table 9 indicates the job-wise conformance outcome. At 50% tone value, 20% of the files (7/35) conform to the ISO criteria, while at 80% tone value, 54% of the files (19/35) conform to the ISO criteria.

4,5 - The red line is the ISO criterion.

Table 9. Job-wise conformance to ISO criteria by TVI percentiles

TVI		K50	C50	M50	Y50	OK?	K80	C80	M80	Y80	OK?
Job #	Tol.	4	4	4	4		3	3	3	3	
1	Δ	1.3	2.8	1.2	1.9	Y	0.7	1.5	0.9	0.9	Y
2	Δ	4.3	5.6	4.0	2.3	N	1.0	2.5	0.8	0.4	Y
3	Δ	1.1	2.1	2.0	1.1	Y	2.1	2.1	1.4	5.4	N
4	Δ	8.6	8.6	1.5	1.1	N	2.2	1.8	0.2	1.1	Y
5	Δ	10.5	5.3	0.9	2.2	N	3.5	0.3	0.5	0.7	N
6	Δ	3.7	0.8	4.8	0.6	N	0.4	0.2	2.5	0.2	Y
7	Δ	2.2	2.1	8.2	4.6	N	0.1	3.7	8.2	4.1	N
8	Δ	3.1	1.5	9.3	4.6	N	1.3	3.3	8.2	3.6	N
9	Δ	1.5	0.5	0.0	3.1	Y	1.2	2.0	2.5	0.2	Y
10	Δ	3.9	2.7	2.6	7.3	N	0.7	0.8	0.8	2.0	Y
11	Δ	2.8	4.5	3.4	5.0	N	1.3	1.1	1.3	1.1	Y
12	Δ	1.0	0.4	1.4	5.1	N	0.3	0.8	0.2	1.9	Y
13	Δ	7.8	4.7	2.3	2.8	N	0.3	1.1	0.2	1.5	Y
14	Δ	0.0	5.2	3.7	0.3	N	1.6	0.8	3.6	1.1	N
15	Δ	1.7	0.4	1.0	0.2	Y	0.8	2.3	1.5	1.2	Y
16	Δ	4.0	4.9	1.2	6.1	N	4.8	4.4	0.7	5.4	N
17	Δ	4.0	2.0	2.9	6.4	N	1.0	4.5	1.0	4.5	N
18	Δ	1.1	0.9	1.4	2.5	Y	3.7	3.4	3.3	3.9	N
19	Δ	9.7	9.3	9.7	9.0	N	5.1	4.3	3.5	3.1	N
20	Δ	9.4	8.6	9.1	8.4	N	5.3	3.8	3.1	3.5	N
21	Δ	9.1	9.1	6.3	7.2	N	2.7	2.9	1.3	0.7	Y
22	Δ	1.6	3.2	1.3	3.3	Y	2.5	3.0	3.7	0.4	N
23	Δ	6.9	4.2	4.4	2.1	N	0.7	0.9	0.4	2.1	Y
24	Δ	5.1	3.3	4.0	4.4	N	1.7	0.9	1.8	5.1	N
25	Δ	6.5	3.3	3.2	5.0	N	2.7	0.0	2.0	5.2	N
26	Δ	4.4	4.6	0.6	1.5	N	3.4	0.3	1.3	1.4	N
27	Δ	7.6	3.4	2.3	0.6	N	4.2	0.2	2.6	1.2	N
28	Δ	1.8	0.7	2.3	4.5	N	0.7	0.6	2.0	2.2	Y
29	Δ	5.5	0.7	1.4	6.5	N	2.6	1.5	0.4	1.5	Y
30	Δ	1.9	2.8	4.5	3.1	N	0.5	1.6	1.4	0.5	Y
31	Δ	3.2	0.7	1.0	1.7	Y	1.5	0.6	0.1	0.5	Y
32	Δ	0.2	1.8	4.6	0.5	N	1.8	0.9	1.4	1.0	Y
33	Δ	5.5	6.5	11.0	8.0	N	2.2	2.0	3.5	3.5	N
34	Δ	7.9	3.1	4.0	3.0	N	2.1	1.7	1.2	0.1	Y
35	Δ	3.7	1.2	4.3	2.6	N	2.2	2.1	2.4	2.9	Y

Discussion

The TVI conformance of 65% at 50% tone value is lower than the TVI conformance of 75% at 80% tone value, even though the tolerance at 50% (4%) is greater than that at 80% (3%). TVI is a parameter defined in ISO, but not followed rigorously in the US. Most U.S. printers calibrate their presses using near-neutral methods. To reduce the conformance assessment effort, it is recommended that only 50% tone value is required.

Deviation of OK Print—Mid-tone Spread

Objective

Examine the distribution of deviation on mid-tone spread.

Input

The mid-tone spread values (50% only) of 35 jobs.

Procedure

1. Plot the mid-tone spread values of 35 jobs as CRF.

Results

The CRF of mid-tone spread for all 35 jobs is shown in Figure 17. The mid-tone spread conformance is determined by the tolerance of 5. Sixty percent of the files (21/35) conform to the ISO criterion.

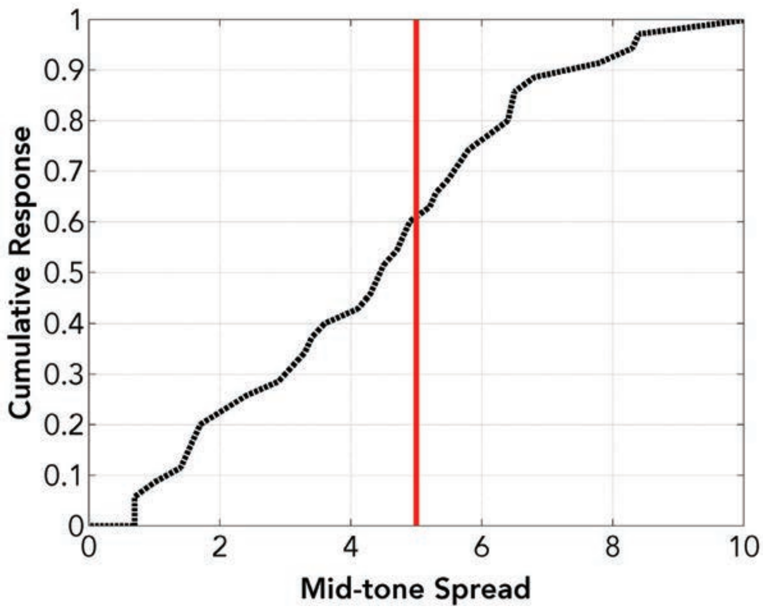


Figure 17. CRF of mid-tone spread[6]

Discussion

Low TVI deviation conformance (65%) also leads to low mid-tone spread conformance (60%).

Tone Reproduction Limits

Objective

Examine halftone dot patterns from 3% to 97% printed in a consistent and uniform manner.*

Input

The CIELAB values of paper, 2%, 3%, 5%, 7%, and 10% of CMYK and 90%, 95%, 98%, and solid of CMYK of 35 jobs.

***Note:** The default method is by visual examination. There is no established method that assesses tone reproduction limits quantitatively. What follows is an innovative approach to screen or detect jobs that require visual examination. The method uses one standard deviation of the database to flag the low tonality contrast samples. Since only the low end of tone contrast is interested, the method will detect about 1/6 of the database for further visual examination.

6 - The red line is the ISO specified tolerance.

Procedure

1. Use the 0% and 100% values as a reference to compute ΔE and ΔC between these values and their neighbors.
2. Plot ΔE and ΔC as a function of %dot and select either ΔE or ΔC as the parameter for tone reproduction limits analysis.

Results

Figures 18-21 show ΔEs and ΔCs as a function of dot areas for the highlight and shadow regions for KCMY channels of all 35 jobs. By visually observing the slopes, tonality is consistently resolved if there is a linear change in the Δ. There are some reversed tonalities for the Y channel, which could be caused by spatial non-uniformity. It is clear that ΔE, particularly for Black (K), is a better metric for judging tonal differences than ΔC.

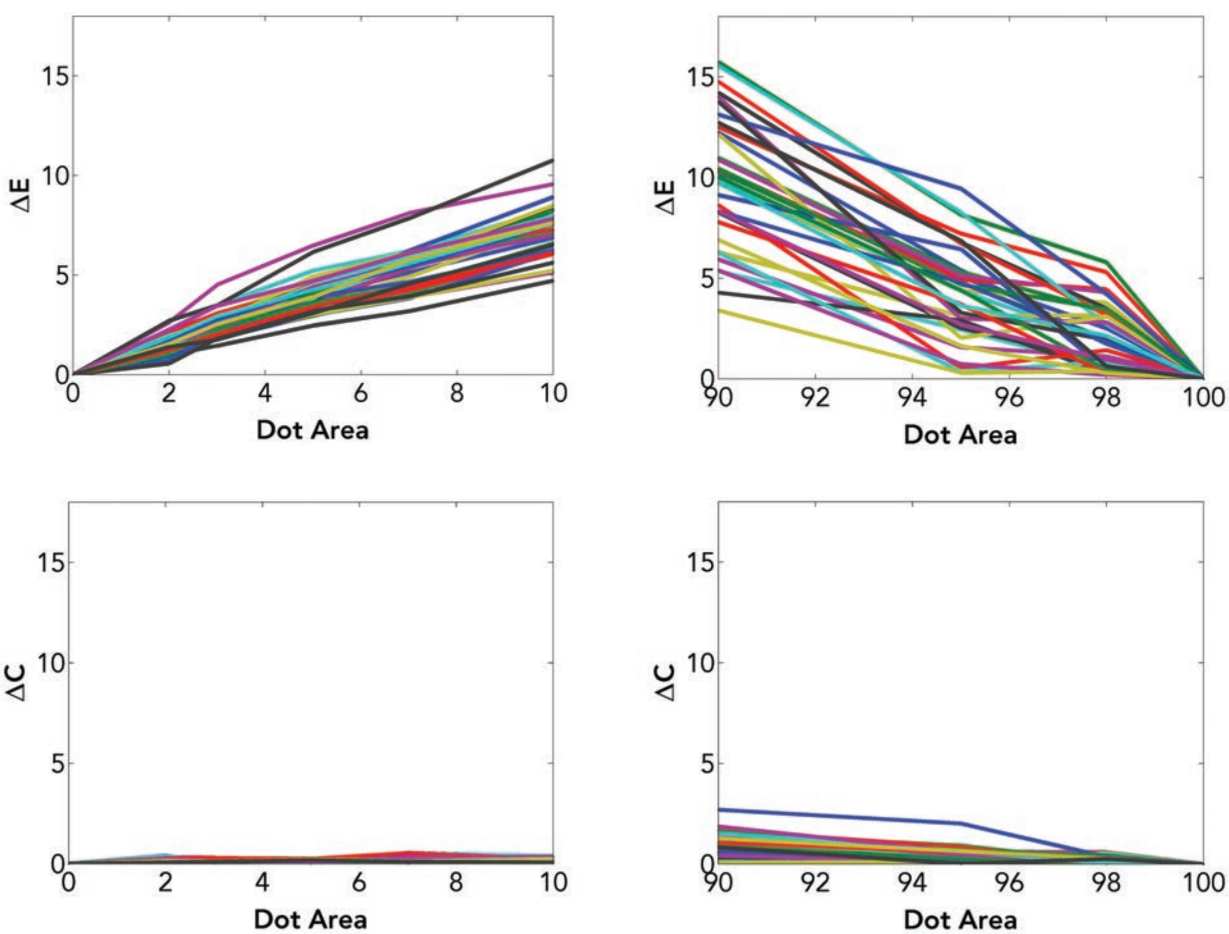


Figure 18. The ΔEs and ΔCs as a function of dot areas for the highlight (left) and shadow (right) regions for the K channel

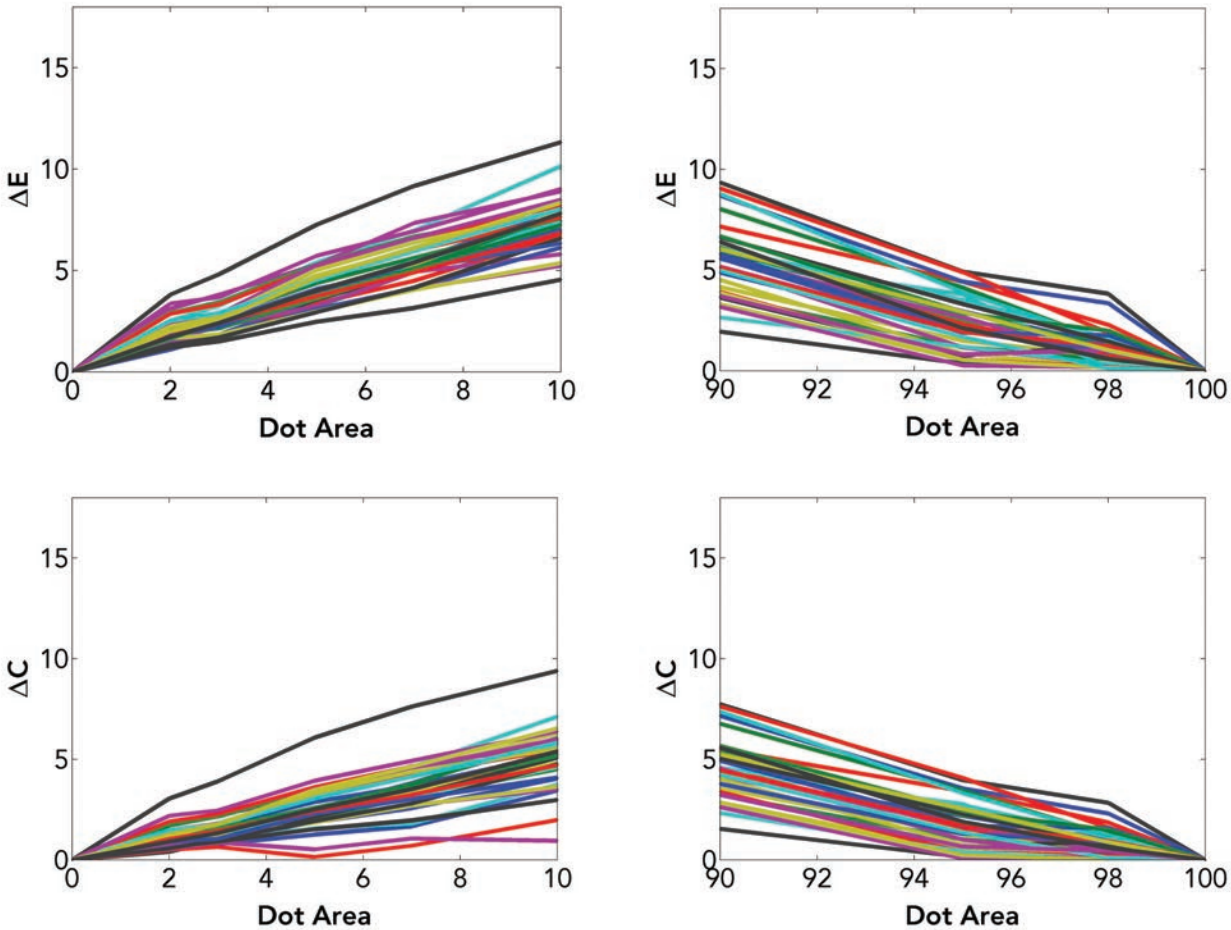


Figure 19. The ΔEs and ΔCs as a function of dot areas for the highlight (left) and shadow (right) regions for the C channel

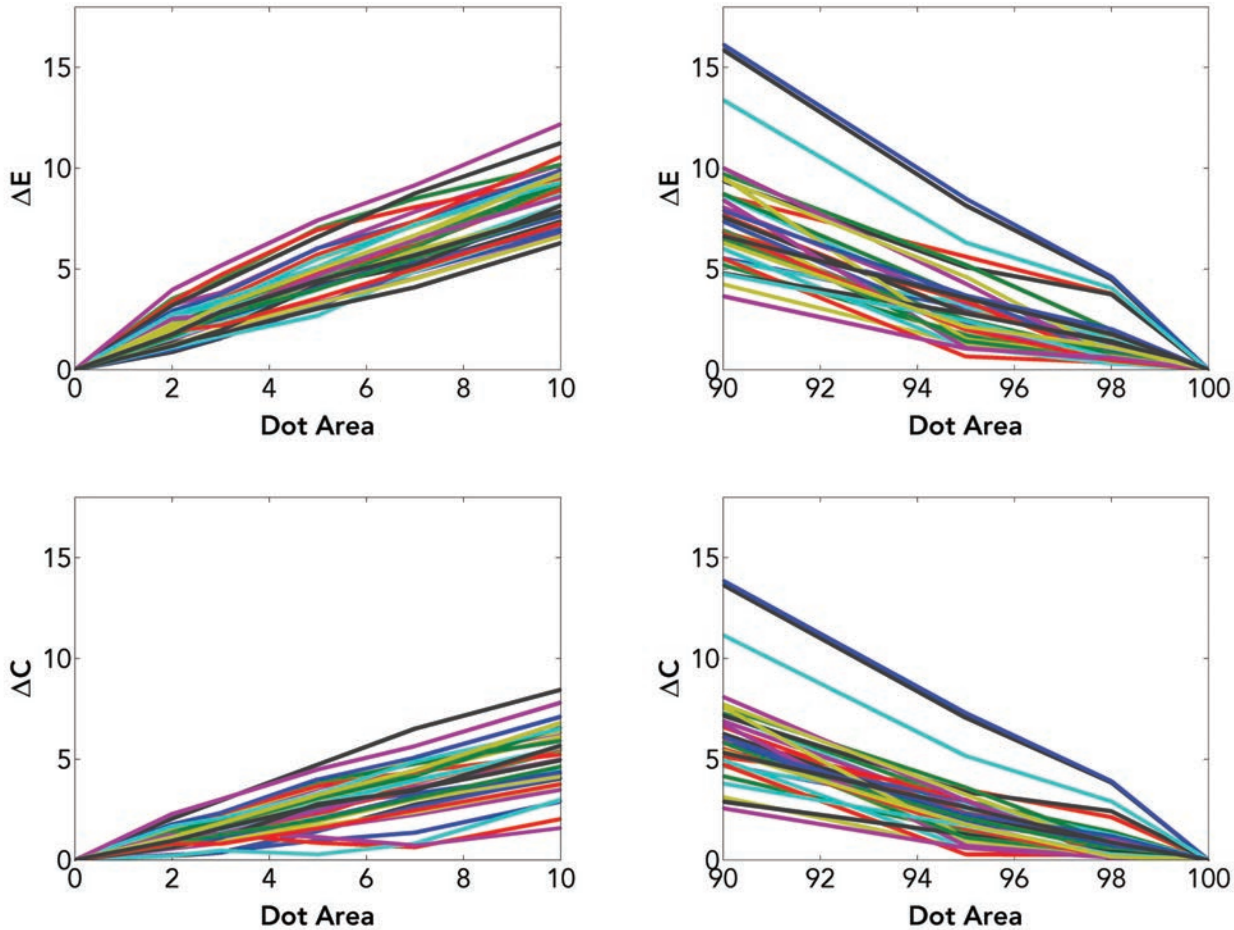


Figure 20. The ΔEs and ΔCs as a function of dot areas for the highlight (left) and shadow (right) regions for the M channel

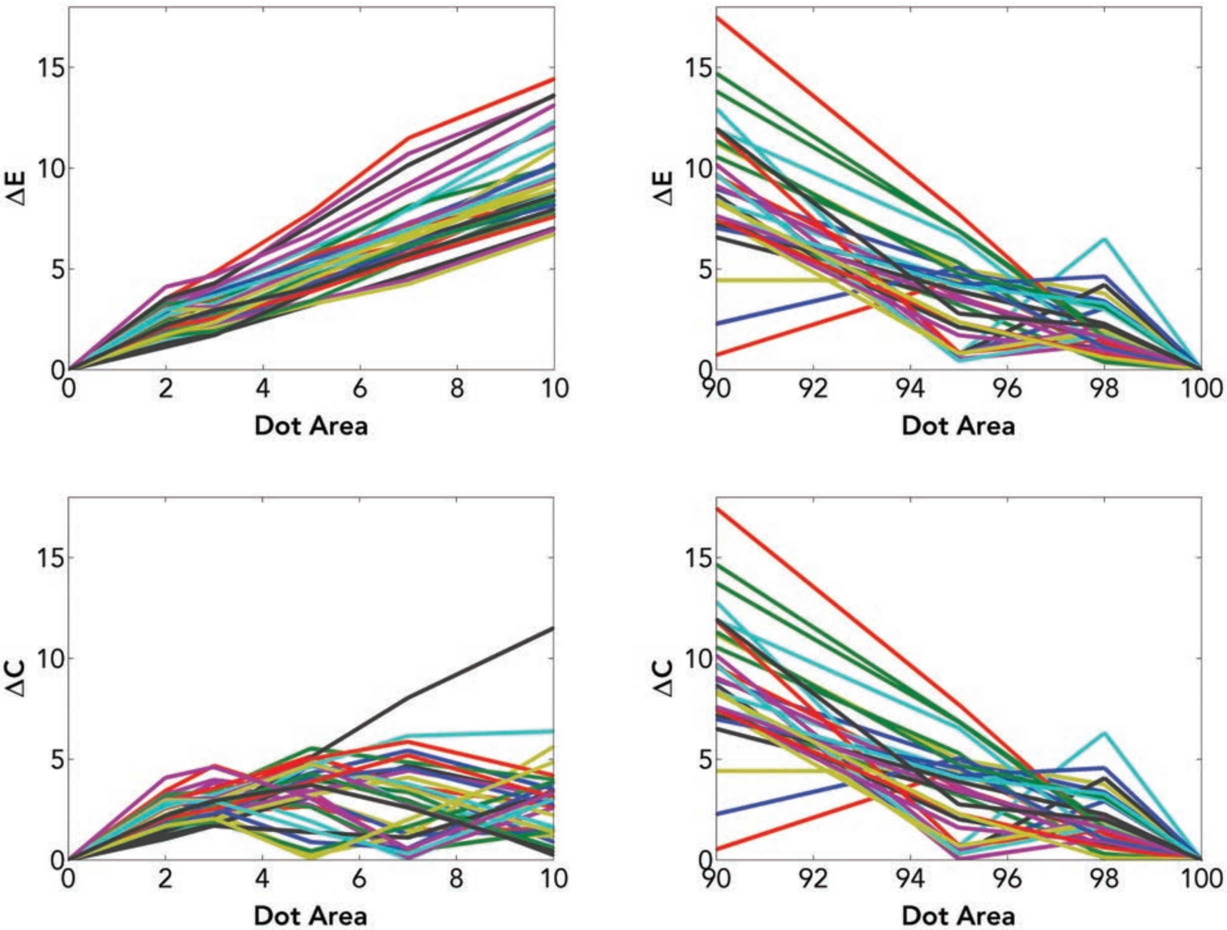


Figure 21. The ΔEs and ΔCs as a function of dot areas for the highlight (left) and shadow (right) regions for the Y channel

Tables 10 and 11 show the mean and standard deviation of ΔEs between references (0% or 100%) and their neighbors for all channels of the 35 jobs. The line of mean values minus one standard deviation form a threshold that can be used to flag those jobs having low tonal contrast that need further visual verification—about 1/6 or 17% by each region of the database. The reason to take only the lower side (-1 standard deviation) is that the higher side should be differentiated.

Table 10. Mean ΔEs and their standard deviations of KCMY channels from 0 – 10% tone reproduction

Percentage (Reference: 0%)	K		C		M		Y	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
0%	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
2%	1.5	0.53	2.0	0.64	2.1	0.79	2.3	0.77
3%	2.4	0.63	2.5	0.70	2.8	0.91	2.9	0.87
5%	4.0	0.86	4.2	0.98	4.6	1.20	5.0	1.16
7%	5.3	1.07	5.5	1.14	6.2	1.26	6.9	1.65
10%	7.2	1.24	7.5	1.31	8.6	1.40	9.5	2.02

Table 11. Mean ΔEs and their standard deviations of KCMY channels from 90 - 100% tone reproduction

Percentage (Reference: 100%)	K		C		M		Y	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
90%	9.9	3.25	5.5	1.82	7.8	2.82	9.0	3.21
95%	4.2	2.35	2.3	1.38	3.2	1.89	3.4	2.06
98%	2.2	1.57	1.1	0.87	1.4	1.23	2.0	1.33
100%	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00

The thresholds formed by mean values minus one standard deviation are shown in Figures 22-25 (n=35). The figures are helpful to indicate the low tonal contrast points graphically.

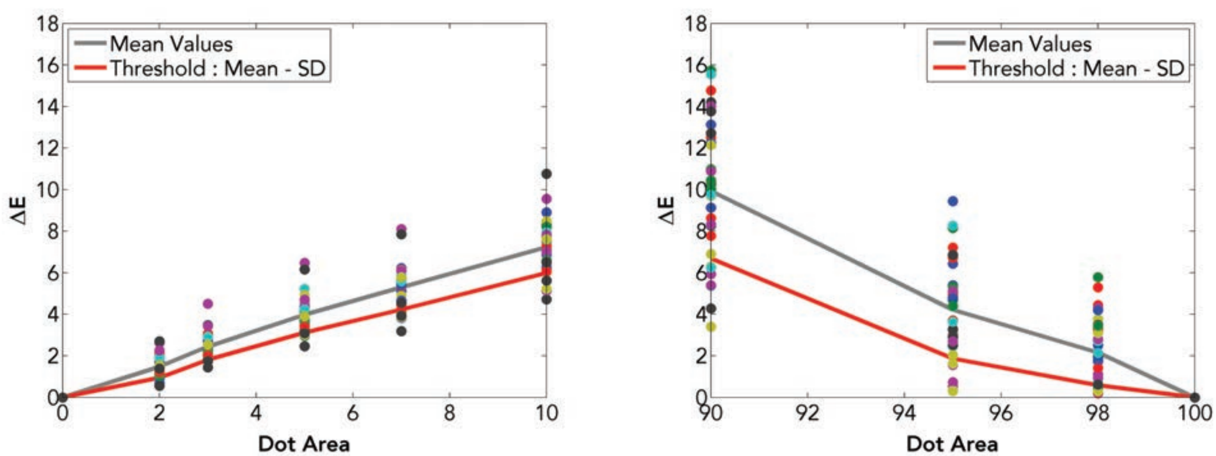


Figure 22. The K channel threshold for flagging low tonal contrast for the highlight (left) and shadow (right) regions

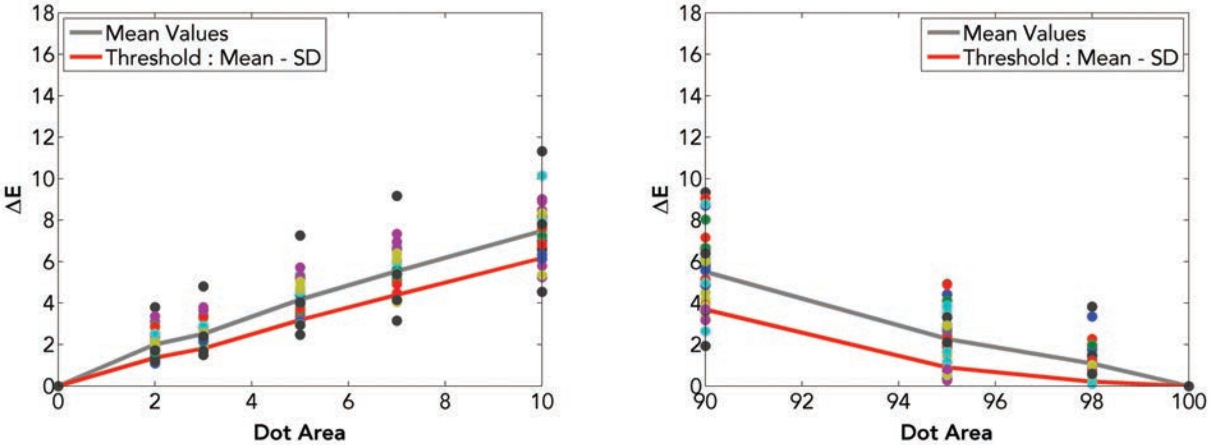


Figure 23. The C channel threshold for flagging low tonal contrast for the highlight (left) and shadow (right) regions

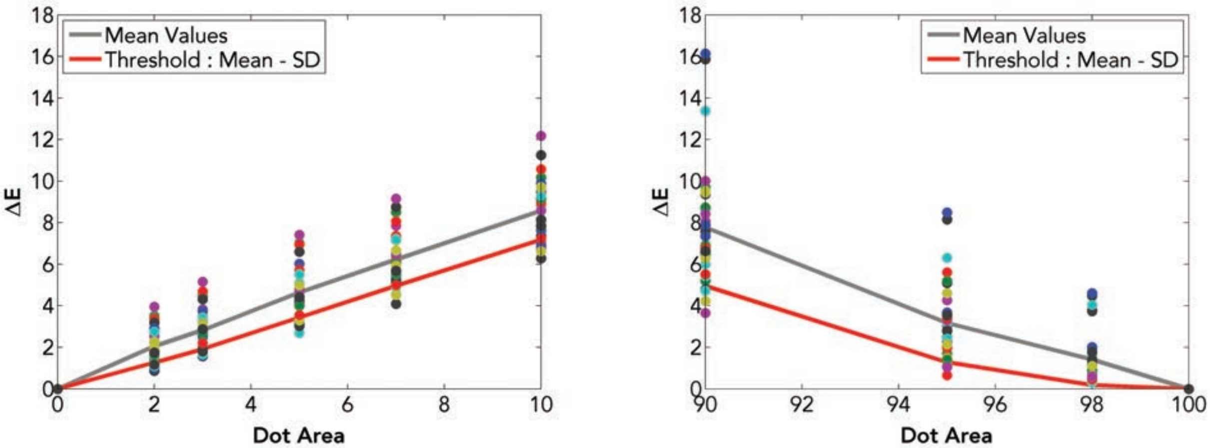


Figure 24. The M channel threshold for flagging low tonal contrast for the highlight (left) and shadow (right) regions

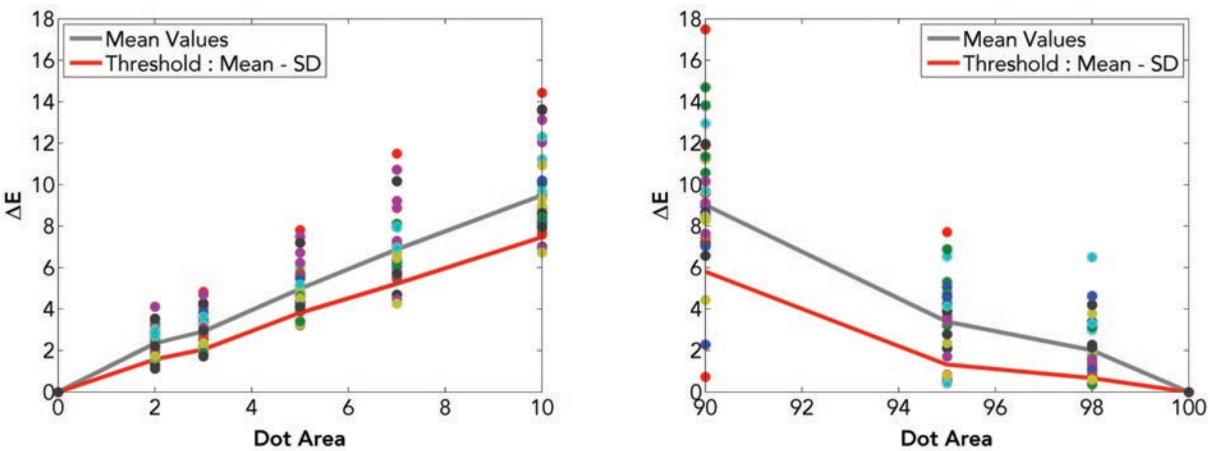


Figure 25. The Y channel threshold for flagging low tonal contrast for the highlight (left) and shadow (right) regions

Table 12 shows the conformance of reproduction limits by taking the threshold curves derived from the database. It should be noted that only the range between the 3% and 97% dot areas is taken into consideration. For region-wise judgment (highlight or shadow region for any color), the percentages of conformance are between 66% and 89%, where the Y shadow performs worst. For each channel in either region, between 10−30% of the jobs required further visual judgment, with an average of one out of six jobs (17%).

Table 12. Conformance of reproduction limits to derived threshold curves by color channel and image region

Category	Highlight				Shadow			
	K	C	M	Y	K	C	M	Y
# of files that conform	27	29	27	31	26	26	27	23
% conformance	77%	83%	77%	89%	74%	74%	77%	66%

By visually evaluation of the plots above, the threshold curve is quite straight. Therefore, to simplify the screening threshold, a straight line with 6 ΔE at 10% and 0 ΔE at 0% dot area is used as a threshold for the highlight region. A straight line with 3 ΔE at 90% and 0 ΔE at 100% dot area is used as a threshold for the shadow region. The screening threshold allows the derivation of a quantitative method to detect small portions that require visual verification. The conformance of region-wise judgment is shown in Table 13, and the plots with the simplified and generalized thresholds are shown in Figures 26-29.

Table 13. Conformance of reproduction limits to straight-line thresholds by color channel and image region

Category	Highlight				Shadow			
	K	C	M	Y	K	C	M	Y
# of files that conform	29	29	33	35	31	23	28	24
% conformance	83%	83%	94%	100%	89%	66%	80%	69%

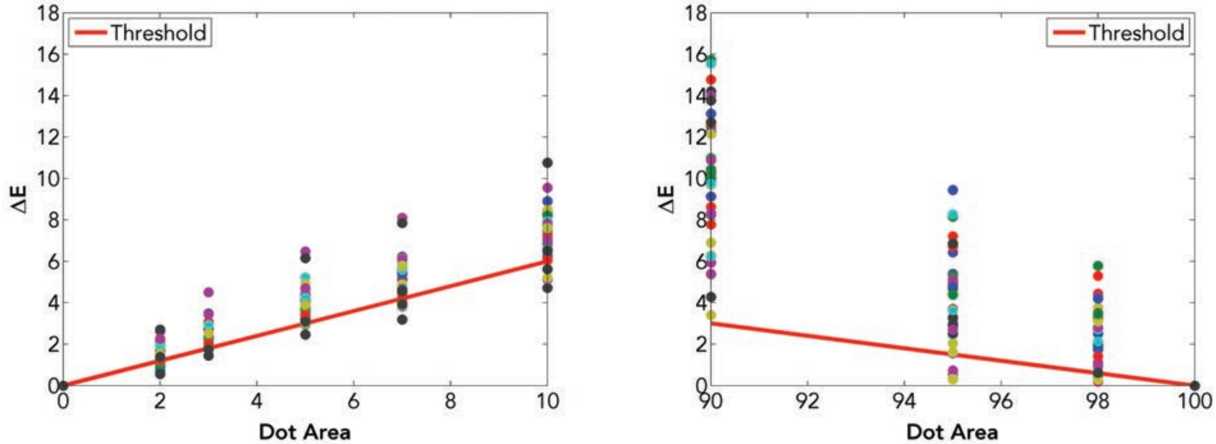


Figure 26. The straight-line threshold for flagging low tonal contrast in the K channel for the highlight (left) and shadow (right) regions

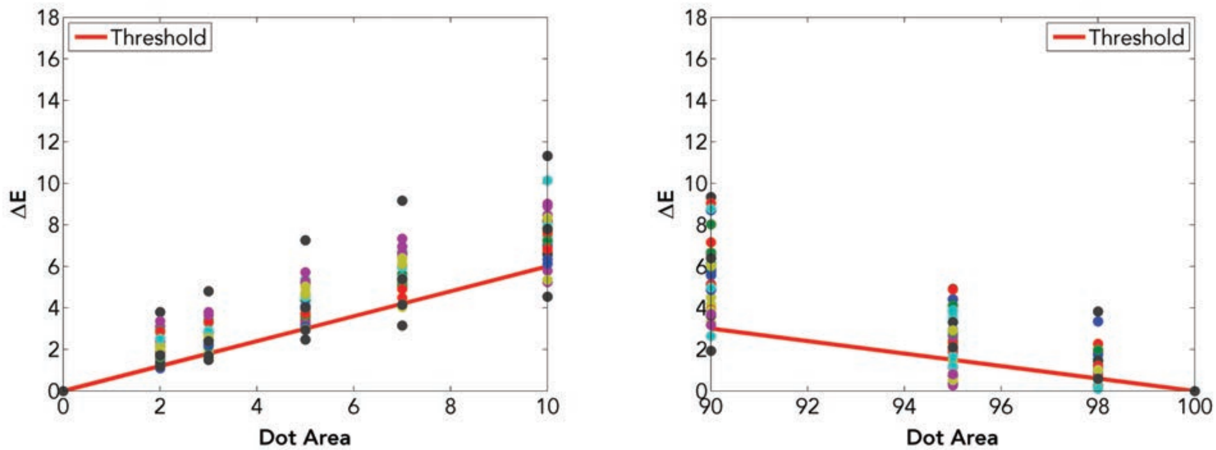


Figure 27. The straight-line threshold for flagging low tonal contrast in the C channel for the highlight (left) and shadow (right) regions

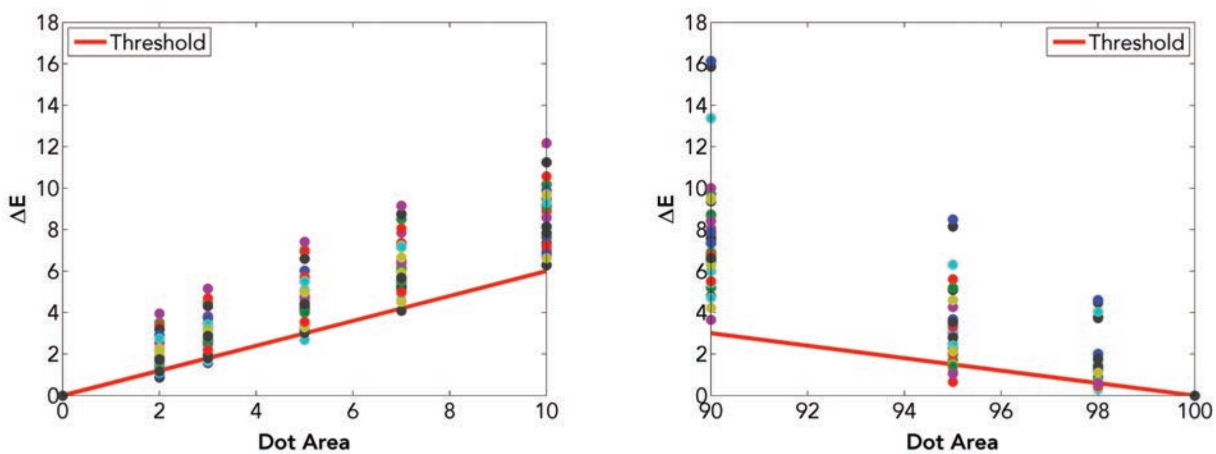


Figure 28. The straight-line threshold for flagging low tonal contrast in the M channel for the highlight (left) and shadow (right) regions

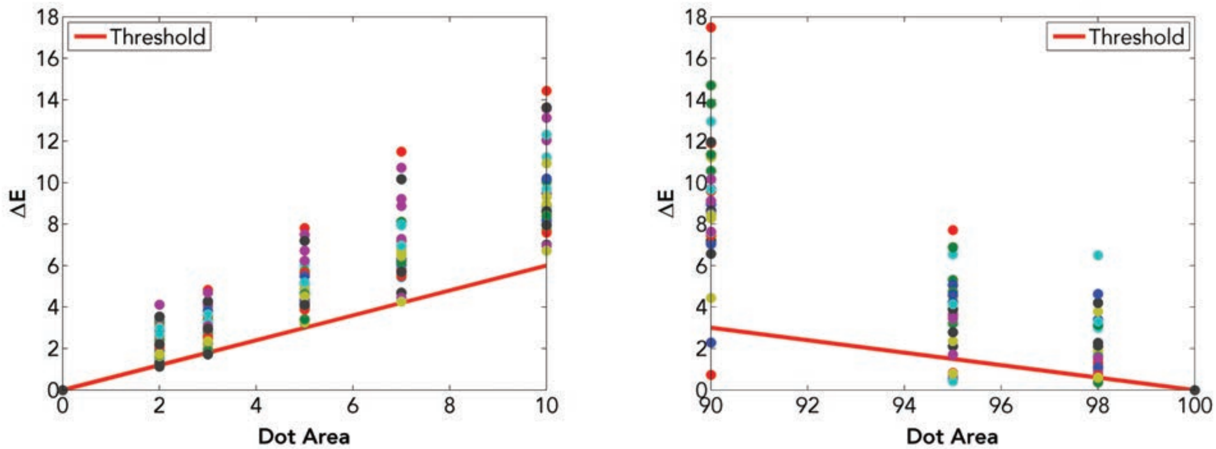


Figure 29. The straight-line threshold for flagging low tonal contrast in the Y channel for the highlight (left) and shadow (right) regions

In terms of job-wise conformance, 37% of the jobs (13/35) do not require visual judgment, which can save a certain degree of time and resources. (The tables for judging the conformance of all 35 jobs are shown in Appendix A.) The remaining 63% (20/35) require further visual judgment, due to at least one failure out the eight cases, i.e., 2 image regions (highlight/shadow) x 4 color channels (CMYK). Further research may be focused on conducting psychophysical experiments to either confirm the suggested tolerance or to find a more appropriate tolerance. Overall, this proposed method can help to avoid human error, and is effective for judging production limits conformance.

Near-Neutral Variation

Objective

Examine the colorimetric variation of near-neutral triplets relative to substrate-based grey ramp (SBGR).

Input

Specific near-neutral triplets, as shown in Table 14, available from the IT8.7/4 target and input corresponding measurements of the 35 jobs.

Table 14. Near-neutral triplet measurements

Triplet Type	ID of IT8.7/4	C	M	Y	K
Paper	1	0	0	0	0
Quarter-tone	192	30	20	20	0
Mid-tone	1611	50	40	40	0
Three-quarter-tone	1369	80	65	65	0
CMY solid	729	100	100	100	0

Procedure

By using measurement data (n=35), we can study variation.

1. Plot grey reproduction curves (i.e., a^* and b^* values as a function of %dot (cyan) of all five triplets (n=35)).
2. Plot individual grey reproduction curves versus their substrate-based grey ramps or SBGR (n=35).
3. Identify the 3 jobs demonstrating best and worst grey reproduction behavior as shown in the SBGR.
4. Plot an a^*b^* scatter diagram for each of the five triplets.

Note: Substrate-based grey ramp (SBGR) is a grey ramp starting from non-neutral paper white a^* and b^* values that gradually changes to less chromatic values as L^* decreases. To calculate SBGR, the only input is paper color as shown in the equation below. To visualize it, %dot is used as the x-axis in the plot. An example of the SBGR of substrate color (a^*,b^*) = (2,-4) is shown in Figure 30.

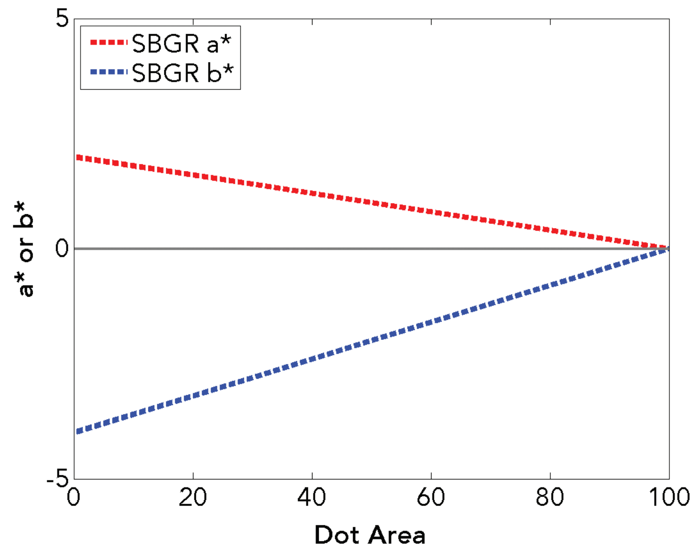


Figure 30. An example of the SBGR of substrate color (a^*,b^*) =(2,-4).

Results

Figure 31 shows the distribution of measured a* and b* values as a function of the dot area of all 35 jobs. It is a way to show the distribution of the triplets together. The figure indicates that, as dot areas increase, triplets vary more widely.

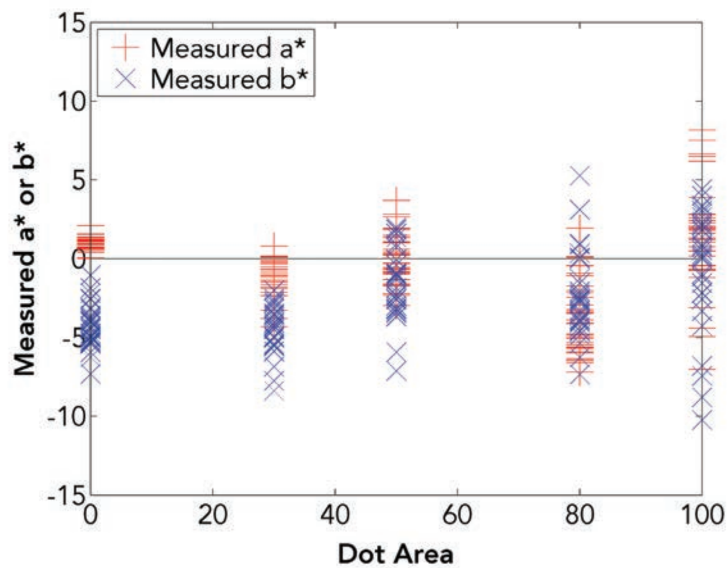


Figure 31. Distribution of measured a* and b* values as a function of the dot area

The 35 individual grey reproduction curves and their substrate-based grey ramps (SBGR) are shown in Appendix B. Variation at 0% indicates the variation of substrate color.

By visually judging the performance at quarter-tone and mid-tone, the three jobs demonstrating the best grey reproduction conformance are jobs 17, 32, and 19. The three jobs demonstrating the worst grey reproduction conformance are jobs 8, 18, and 24. These measurements are shown in Figures 32 and 33. Note that the SBGR is an ideal case, and, in reality, the grey ramp usually has the fishtail effect at high dot areas.

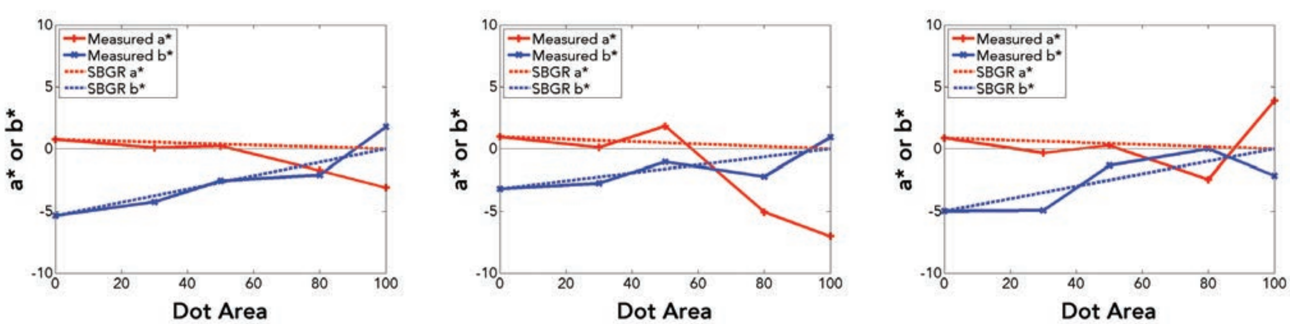


Figure 32. Three jobs demonstrating the best grey reproduction conformance

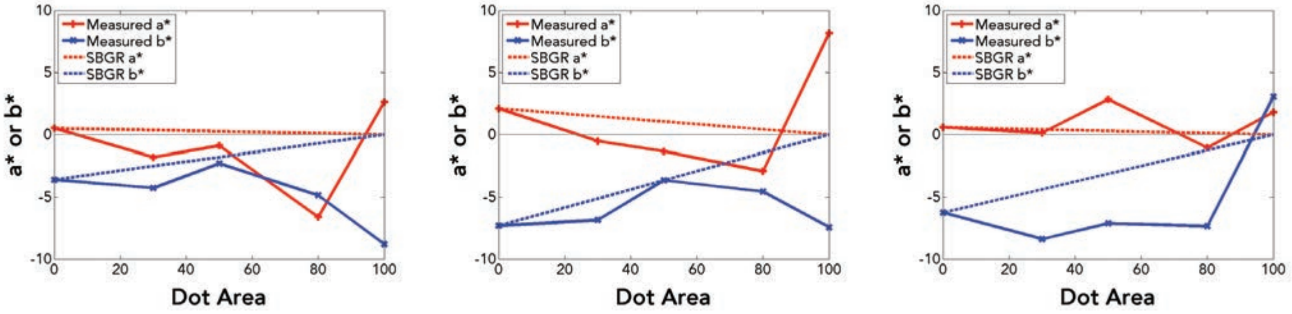


Figure 33. Three jobs demonstrating the worst grey reproduction conformance

The distribution of near-neutrals of 35 jobs is shown in Figure 34. Again, as the amount of inks increase, the degrees of scatter increase. Figure 34 (f) shows the distribution of chromaticity of all triplets in one graph. The fact that CMY solids have the largest variation should be excluded from the grey reproduction conformance assessment.

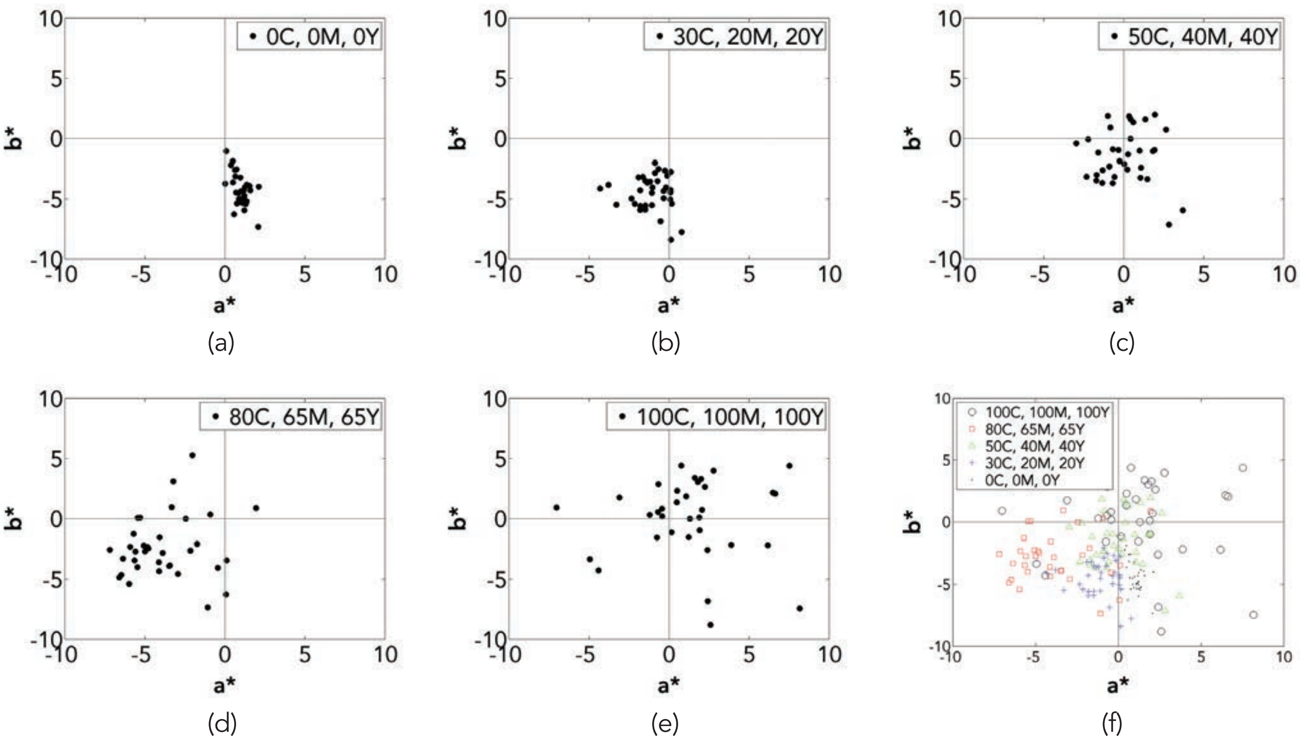


Figure 34. Distribution of near-neutrals

(a) Chromatic variation at 0% reflects color differences in paper white.
(b) Quarter-tone greys, while still bluish, start to migrate towards the origin.
(c) Mid-tone greys are centered around the origin.
(d) Three-quarter-tone greys are affected by printing variations which exhibit larger variation than mid-tone greys.
(e) CMY solids, although rendered grey by the GRACoL data set at average, vary widely, as depicted in the standard deviation. In fact, 1-D (TVI or grey balance) correction curves have no influence when CMY overprint solids are not neutral.
(f) The a^*b^* scatter diagram of all five levels of triplets.

The statistical summary (mean and standard deviation of a^* and b^*) of grey reproduction relative to the three levels of triplets is shown in Table 15. By judging from the starting point (1.0a^*, -4.4b^*) to the ending point (1.3a^*, -0.3b^*), the average of the grey reproduction migrates towards neutral as expected, but the variation of the grey reproduction increases as the tonality darkens.

Table 15. Mean and standard deviation of a* and b* values by near-neutral triplet

Triplet Type	Mean		Std. Dev.	
	a^*	b^*	a^*	b^*
Paper	1.0	-4.4	0.46	1.29
Quarter-tone	-1.1	-4.5	1.14	1.45
Mid-tone	0.0	-1.5	1.56	2.19
Three-quarter-tone	-3.8	-2.4	2.23	2.55
CMY solid	1.3	-0.3	3.30	3.68

Near-Neutral Conformance

Objective

Examine the colorimetric conformance of near-neutral triplets relative to substrate-corrected colorimetric aims (SCCA) and tolerances.

Input

Specific near-neutral triplets available from the IT8.7/4 target and input corresponding measurements of 35 jobs are shown in Table 16.

Table 16. Near-neutral triplet and their device values

Triplet Type	ID of IT8.7/4	C	M	Y	K
Paper	1	0	0	0	0
Quarter-tone	192	30	20	20	0
Mid-tone	1611	50	40	40	0
Three-quarter-tone	1369	80	65	65	0
CMY solid	729	100	100	100	0

Procedure

Conformance analysis of grey reproduction can be determined by ΔC_h and ΔL^* between grey triplet measurement and substrate-corrected colorimetric aims or SCCA against the tolerance.

1. Starting from pre-defined triplets, find the target colorimetric aims via the ICC profile of the target data set, i.e., GRACoL (2006) ICC profile under the absolute colorimetric rendering intent.
2. Find the SCCA by applying tristimulus linear correction per ISO 13655. Plot the Δa^* and Δb^* of all five triplets as a function of %dot where $\Delta a^* = a^*(\text{measured}) - a^*(\text{SCCA})$ and $\Delta b^* = b^*(\text{measured}) - b^*(\text{SCCA})$.
3. Calculate ΔL^* and ΔC_h between triplet measurement and SCCA. Plot ΔL^* and ΔC_h as CRF curves for conformance determination.

Results

Table 17 shows the target colorimetric aims of the five triplets based on the GRACoL (2006) data set derived through Photoshop API.

Table 17. Target colorimetric aims of the near-neutral triplets

Triplet Type	ID of IT8.7/4	C	M	Y	K	L*	a*	b*
Paper	1	0	0	0	0	95	0	-2
Quarter-tone	192	30	20	20	0	73	-1	-3
Mid-tone	1611	50	40	40	0	58	0	-1
Three-quarter-tone	1369	80	65	65	0	38	-5	-3
CMY solid	729	100	100	100	0	23	0	0

Figure 35 shows Δa^* and Δb^* between measurement and substrate-corrected colorimetric aims of all five triplets as a function of dot area.

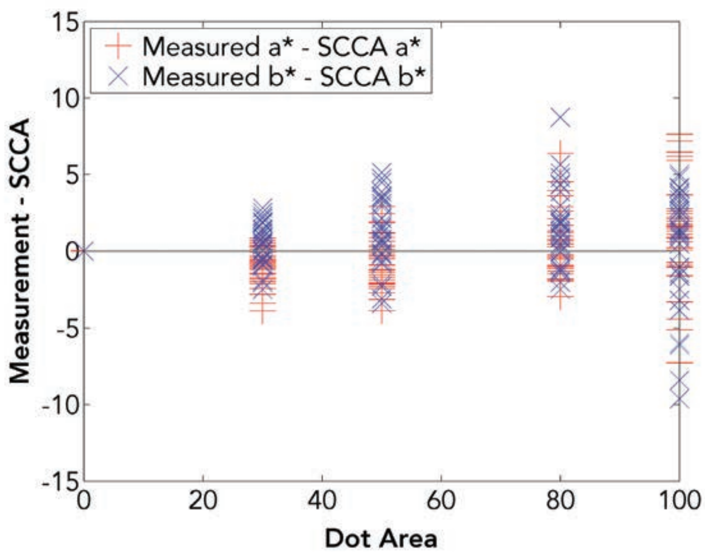


Figure 35. Distribution of Δa^* and Δb^* between measurements and SCCA by dot area

The CRFs of ΔC_h between triplet measurement and SCCA are shown in Figure 36. The 90th percentiles of quarter-tone, mid-tone, and three-quarter-tone are about 3, 4, and 5 ΔC_h respectively.

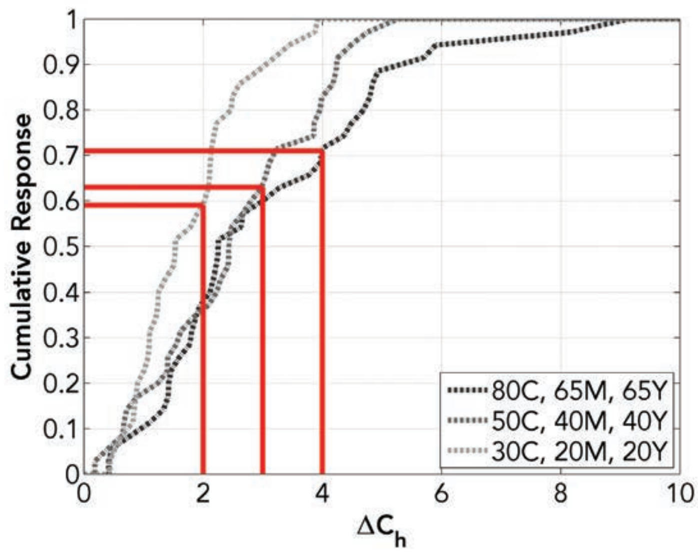


Figure 36. The CRFs of ΔC_h between measurement and substrate-corrected colorimetric aims[7]

The analysis of IDEAlliance's G7 database (Chung & Wang, 2011) recommended that the ΔC_h tolerances of quarter-tone, mid-tone, and three-quarter-tone be 2.0, 3.0, and 4.0 respectively, as indicated by red lines in the figure. Based on these rules, 57% of the database (20/35) passed the 2.0 ΔC_h tolerance at the quarter-tone triplet; 63% (22/35) passed the 3.0 ΔC_h tolerance at the mid-tone triplet; and 71% (25/35) passed the 4.0 ΔC_h tolerance at the three-quarter-tone triplet.

The CRFs of ΔL^* between triplet measurement and SCCA are shown in Figure 37. The 90th percentiles of quarter-tone, mid-tone, and three-quarter-tone are around 4 ΔL^*. Since there is no prior case for ΔL^* tolerance, 2.5 ΔL^* is assumed as the tolerance of quarter-tone, mid-tone, and three-quarter-tone, which is shown as the red line in the figure. Based on this rule, 86%, 57%, and 71% of the database (n=35) passed the 2.5 ΔL^* tolerance at the quarter-tone, mid-tone, and three-quarter-tone triplets, respectively.

7 - The red lines are assumed tolerances.

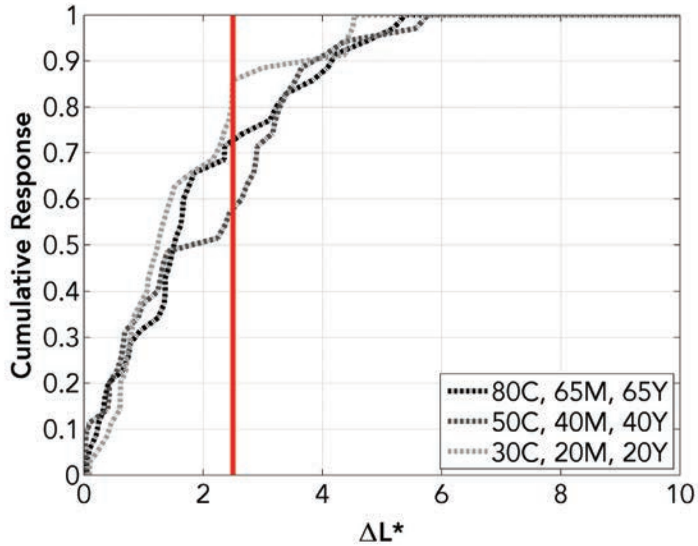


Figure 37. The CRFs of ΔL* between measurement and substrate-corrected colorimetric aims[8]

If conformance is defined such that all three triplets must be in conformance per job for both ΔC_h and ΔL^*, then , as shown in Table 18, only 23% of the database (8/35) pass the grey reproduction requirement. The grey reproduction conformance of the 35 jobs is shown in Appendix C for detail information.

Table 18. Summary of colorimetric conformance of files in PSA database by tone value

Category	ΔL^*_25	ΔL^*_50	ΔL^*_75	ΔC_h_25	ΔC_h_50	ΔC_h_75	Job-wise
	2.5	2.5	2.5	2.0	3.0	4.0	
# of files that conform	30	20	25	20	22	25	8
% conformance	86%	57%	71%	57%	63%	71%	23%

8 - The red line is assumed tolerance.

Discussion

An operational assessment of grey reproduction begins with:

(a) Taking a set of near-neutral CMY triplets available in a control strip,

(b) Printing and measuring these patches colorimetrically,

(c) Plotting a^* and b^* of these triplets against %dot, and

(d) Comparing how close these points are with two straight lines connecting a^* and b^* of the paper (0%) and 100% dot.

Such a comparison is qualitative and is subjective to biases of the pre-determined triplets.

A quantitative approach to grey reproduction conformance assessment is to:

(a) Recognize a characterization data set as the aim,

(b) Find colorimetric values of these near-neutral CMY triplets via the ICC profile of the data set,

(c) Make substrate-correction to align colorimetric aims with the production stock,

(d) Find ΔL^* and ΔC_h between measurement and substrate-corrected aims, and

(e) Decide tolerances based on a well-defined standard.

The colorimetric conformance of grey reproduction of near-neutral triplets relative to substrate-corrected colorimetric aims (SCCA) is shown in Table 19. Since the PSA database is unfiltered, the percentage of conformance is lower than that of filtered databases.

Summaries of Key Findings

Table 19 indicates the percentage of conformance of the PSA database in terms of ISO 12647-2 criteria. The database is not screened. Hence, many jobs fail the ISO criteria for deviation conformances.

Table 19. Percentage conformance of files in PSA database to ISO 12647-2 criteria

Category	Substrate Color	Printed Solids (ΔE & ΔH)	TVI Difference		Mid-tone Spread
			50% TVI	80% TVI	
# of files that conform	11	15	7	19	21
% conformance	31%	43%	20%	54%	60%

The judgment by color is shown in Table 20. The percentages of performance are higher than judgment by job.

Table 20. Percentage conformance of files in PSA database to printed solids and TVI standards by color channel

Category	Printed Solids							TVI							
	ΔE				ΔH			50%				80%			
	K	C	M	Y	C	M	Y	K	C	M	Y	K	C	M	Y
# of files that conform	31	26	30	19	32	22	30	20	22	24	20	28	28	27	24
% conformance	89%	74%	86%	54%	91%	63%	86%	57%	63%	69%	57%	80%	80%	77%	69%

Table 21 indicates the conformance of tone reproduction limits based on the proposed straight-line method.

Table 21. Percentage conformance of files in PSA database to tone reproduction limits by image region and color channel

Category	Highlight				Shadow				Job-wise
	K	C	M	Y	K	C	M	Y	
# of files that conform	29	29	33	35	31	23	28	24	13
% conformance	83%	83%	94%	100%	89%	66%	80%	69%	37%

Table 23 indicates the conformance of grey reproduction.

Table 23. Percentage conformance of files in PSA database to grey reproduction standards by tone value

Category	ΔL^*_25	ΔL^*_50	ΔL^*_75	ΔC_h_25	ΔC_h_50	ΔC_h_75	Job-wise
	2.5	2.5	2.5	2.0	3.0	4.0	
# of files that conform	30	20	25	20	22	25	8
% conformance	86%	57%	71%	57%	63%	71%	23%

References

Chung, R., & Wang, Y. (2011). *Statistical analyses of the IDEAlliance G7 master printer database* (in press). Rochester, NY: Printing Industry Center at RIT.

Fogra. (2010). *Process Standard Offset (PSO) database* [Database].

ISO 12647-2-- Graphic technology -- Process control for the production of half-tone colour separations, proof and production prints - Part 2: Offset lithographic processes.

ISO 13655 -- Graphic technology -- Spectral measurement and colorimetric computation for graphic arts images.

X-Rite. (2006, March). *NetProfiler® instrument management software*. Retrieved from http://www.xrite.com/documents/literature/gmb/en/100_netprofiler_en.pdf

X-Rite. (2010, March). *The new X-Rite standard for graphic arts (XRGA)*. Retrieved from http://www.xrite.com/Documents/Literature/EN/L7-462_XRGA_Whitepaper_FINAL_EN.pdf

Acknowledgments

The authors wish to express their appreciation to the following individuals and organizations: Dr. Patricia Sorce, RIT Printing Industry Center, for her support and publishing this research as a monograph; Mr. Jürgen Gemeinhardt, Fogra, for his technical support and sharing of the PSO database; and Mr. Robert Eller, RIT Visiting Professor, for his encouragement and review of the manuscript.

Appendix A. Job-Wise Conformance of Tone Reproduction Limits

The following tables show examples of using the mentioned thresholds to check the conformance of production limits of KCMY channels within each job (n=35). It should be noted that only the range between 3% and 97% dot area is taken into consideration.

BlacK		2%	3%	5%	7%	10%	OK?
#	Tol.	-	-	3.0	4.2	6.0	
1	Δ	0.9	2.2	3.9	5.1	6.9	Y
2	Δ	1.0	1.9	3.0	4.1	6.3	N
3	Δ	1.0	1.9	3.3	4.2	6.1	Y
4	Δ	2.2	3.5	5.2	6.2	8.3	Y
5	Δ	2.6	4.5	6.5	8.1	9.6	Y
6	Δ	1.1	2.2	3.5	4.9	7.5	Y
7	Δ	1.1	2.0	3.7	5.9	8.3	Y
8	Δ	1.2	2.0	3.9	6.2	8.9	Y
9	Δ	1.5	2.7	4.3	5.7	7.7	Y
10	Δ	1.3	2.4	3.5	5.4	7.5	Y
11	Δ	0.9	2.2	3.8	5.6	7.4	Y
12	Δ	1.3	2.4	3.6	5.4	7.1	Y
13	Δ	2.1	3.0	4.7	5.8	8.5	Y
14	Δ	1.0	1.5	2.5	3.2	4.7	N
15	Δ	0.9	1.8	3.0	3.8	6.1	N
16	Δ	2.0	3.0	4.1	5.5	7.2	Y
17	Δ	2.1	3.1	4.4	6.1	7.3	Y
18	Δ	1.4	2.0	3.4	4.5	6.3	Y
19	Δ	1.3	2.0	3.0	3.9	5.1	N
20	Δ	1.3	1.9	3.0	3.9	5.2	N
21	Δ	2.7	3.5	6.2	7.9	10.8	Y
22	Δ	0.7	2.1	3.9	4.7	6.2	Y
23	Δ	1.3	2.2	4.1	5.5	8.2	Y
24	Δ	1.9	2.7	4.5	6.1	7.6	Y
25	Δ	2.0	2.7	4.5	5.9	8.0	Y
26	Δ	1.6	2.4	4.4	5.6	7.0	Y
27	Δ	1.7	2.6	4.9	6.1	7.7	Y
28	Δ	0.6	1.8	3.2	3.9	5.6	N
29	Δ	1.7	2.7	4.3	5.4	7.6	Y
30	Δ	1.0	2.3	3.6	4.5	6.6	Y
31	Δ	1.2	2.0	3.4	4.4	6.1	Y
32	Δ	1.9	2.9	4.3	5.6	7.6	Y
33	Δ	2.3	3.4	4.7	6.1	7.8	Y
34	Δ	1.5	2.5	3.9	5.8	7.6	Y
35	Δ	1.4	1.8	3.1	4.6	6.5	Y

BlacK		90%	95%	98%	OK?
#	Tol.	3.0	1.5	-	
1	Δ	10.3	5.1	2.5	Y
2	Δ	10.3	4.8	2.0	Y
3	Δ	12.5	7.2	5.3	Y
4	Δ	5.4	2.4	0.5	Y
5	Δ	5.9	1.6	1.1	Y
6	Δ	9.7	4.4	3.8	Y
7	Δ	14.2	6.8	3.5	Y
8	Δ	12.3	5.4	1.7	Y
9	Δ	11.0	5.3	3.3	Y
10	Δ	10.4	4.9	4.4	Y
11	Δ	9.9	4.4	1.9	Y
12	Δ	10.9	5.1	4.3	Y
13	Δ	6.3	3.1	3.2	Y
14	Δ	8.3	2.5	0.9	Y
15	Δ	9.1	6.4	0.4	Y
16	Δ	15.7	8.1	5.8	Y
17	Δ	14.8	6.7	3.2	Y
18	Δ	15.5	8.3	2.7	Y
19	Δ	14.0	3.0	2.8	Y
20	Δ	12.2	2.0	3.1	Y
21	Δ	4.3	2.9	0.3	Y
22	Δ	13.1	9.4	4.2	Y
23	Δ	10.4	4.7	3.5	Y
24	Δ	8.6	0.5	1.4	N
25	Δ	6.3	0.4	0.8	N
26	Δ	5.4	0.7	0.2	N
27	Δ	3.4	0.3	0.4	N
28	Δ	13.8	3.3	1.9	Y
29	Δ	8.3	4.8	1.8	Y
30	Δ	10.0	4.4	0.4	Y
31	Δ	7.8	3.7	0.3	Y
32	Δ	9.7	3.6	2.1	Y
33	Δ	8.3	2.7	1.0	Y
34	Δ	6.9	1.6	0.3	Y
35	Δ	12.7	6.9	0.6	Y

Cyan		2%	3%	5%	7%	10%	OK?
#	Tol.	-	-	3.0	4.2	6.0	
1	Δ	1.6	2.2	3.8	5.3	6.9	Y
2	Δ	1.3	1.6	3.2	4.9	7.7	Y
3	Δ	1.3	1.8	3.4	4.5	6.7	Y
4	Δ	2.5	3.3	5.4	7.0	10.1	Y
5	Δ	3.1	3.8	5.3	7.3	8.9	Y
6	Δ	1.9	2.5	3.9	5.3	7.3	Y
7	Δ	1.2	1.8	3.6	5.0	7.5	Y
8	Δ	1.1	1.8	3.7	5.4	8.1	Y
9	Δ	2.2	2.7	4.4	5.6	7.4	Y
10	Δ	1.8	2.1	3.6	5.1	6.6	Y
11	Δ	1.8	2.3	3.9	5.4	7.4	Y
12	Δ	1.6	2.2	3.2	4.9	5.8	N
13	Δ	1.9	2.7	4.8	6.0	8.4	Y
14	Δ	1.2	1.5	2.5	3.2	4.5	N
15	Δ	1.4	1.8	3.1	4.1	6.1	N
16	Δ	2.9	3.4	5.3	6.7	7.9	Y
17	Δ	2.9	3.3	5.2	6.6	8.2	Y
18	Δ	1.9	2.4	4.0	5.1	7.3	Y
19	Δ	1.6	1.8	2.9	4.1	5.2	N
20	Δ	1.7	1.8	3.0	4.1	5.4	N
21	Δ	3.8	4.8	7.3	9.2	11.3	Y
22	Δ	2.0	2.5	4.1	5.0	7.0	Y
23	Δ	1.9	2.1	3.6	5.1	7.8	Y
24	Δ	2.3	2.7	4.6	6.0	7.6	Y
25	Δ	2.4	2.8	4.7	6.1	8.0	Y
26	Δ	2.4	2.8	5.3	6.6	8.5	Y
27	Δ	2.2	2.7	5.0	6.4	7.9	Y
28	Δ	1.3	1.7	2.9	4.2	6.6	N
29	Δ	1.8	2.2	4.0	5.1	6.3	Y
30	Δ	1.6	2.5	3.8	5.1	7.2	Y
31	Δ	2.0	2.4	3.7	4.9	6.8	Y
32	Δ	2.5	2.9	4.5	6.0	8.0	Y
33	Δ	3.4	3.7	5.7	6.9	9.0	Y
34	Δ	2.0	2.5	4.7	6.1	8.3	Y
35	Δ	1.7	2.4	4.0	5.4	7.8	Y

Cyan		90%	95%	98%	OK?
#	Tol.	3.0	1.5	-	
1	Δ	5.8	3.0	1.3	Y
2	Δ	3.7	1.2	0.6	N
3	Δ	7.2	4.4	2.3	Y
4	Δ	5.5	3.8	0.1	Y
5	Δ	5.2	1.9	1.0	Y
6	Δ	4.2	1.5	0.7	N
7	Δ	9.3	4.9	3.8	Y
8	Δ	8.7	4.4	3.4	Y
9	Δ	6.1	2.5	1.5	Y
10	Δ	5.7	2.3	0.8	Y
11	Δ	6.0	3.5	1.6	Y
12	Δ	5.6	2.7	0.6	Y
13	Δ	3.3	0.5	0.2	N
14	Δ	3.6	0.7	1.2	N
15	Δ	5.8	2.0	1.0	Y
16	Δ	8.0	4.1	1.4	Y
17	Δ	9.1	4.9	1.9	Y
18	Δ	8.8	3.9	1.5	Y
19	Δ	5.2	1.2	0.3	N
20	Δ	4.5	0.9	0.2	N
21	Δ	1.9	0.4	0.3	N
22	Δ	5.6	1.9	1.8	Y
23	Δ	6.0	2.8	2.0	Y
24	Δ	3.9	0.5	0.2	N
25	Δ	2.6	1.2	0.3	N
26	Δ	3.2	0.3	0.2	N
27	Δ	3.9	0.5	0.2	N
28	Δ	6.6	3.3	1.5	Y
29	Δ	4.9	1.9	1.2	Y
30	Δ	6.7	2.9	1.1	Y
31	Δ	5.1	1.9	1.2	Y
32	Δ	5.0	1.7	0.1	Y
33	Δ	3.7	0.8	1.0	N
34	Δ	6.0	2.9	1.0	Y
35	Δ	6.4	2.1	0.6	Y

Magenta		2%	3%	5%	7%	10%	OK?
#	Tol.	-	-	3.0	4.2	6.0	
1	Δ	1.3	1.7	3.2	4.9	6.8	Y
2	Δ	1.5	2.5	4.2	5.5	8.1	Y
3	Δ	1.7	2.4	4.3	6.5	8.8	Y
4	Δ	2.2	2.9	4.7	6.3	8.7	Y
5	Δ	3.2	3.8	6.0	7.9	10.2	Y
6	Δ	2.2	2.8	4.6	6.7	9.1	Y
7	Δ	0.9	1.6	3.2	5.2	7.4	Y
8	Δ	1.0	1.6	3.1	5.1	7.2	Y
9	Δ	2.3	3.2	4.8	6.4	9.3	Y
10	Δ	1.5	2.7	4.8	6.1	9.0	Y
11	Δ	1.1	1.7	2.7	4.9	7.2	N
12	Δ	1.5	2.3	4.2	5.5	7.7	Y
13	Δ	2.6	3.5	5.5	7.1	9.4	Y
14	Δ	1.3	1.8	3.0	4.1	6.3	N
15	Δ	1.9	2.4	4.5	5.3	7.0	Y
16	Δ	3.5	4.5	7.0	8.5	10.2	Y
17	Δ	3.4	4.7	6.9	8.1	9.5	Y
18	Δ	1.6	2.3	4.0	5.7	8.2	Y
19	Δ	1.2	2.0	3.3	4.5	6.7	Y
20	Δ	1.2	2.0	3.3	4.5	6.6	Y
21	Δ	3.2	4.3	6.6	8.8	11.2	Y
22	Δ	2.9	3.7	6.0	7.4	9.9	Y
23	Δ	1.8	2.6	4.5	6.1	9.2	Y
24	Δ	2.5	3.5	5.7	7.4	10.6	Y
25	Δ	2.6	3.3	5.5	7.2	9.7	Y
26	Δ	2.5	2.8	4.7	6.5	8.6	Y
27	Δ	2.3	2.5	4.2	5.9	7.8	Y
28	Δ	1.2	1.9	4.2	5.2	8.1	Y
29	Δ	2.0	2.5	4.1	5.6	7.6	Y
30	Δ	1.6	2.7	4.0	5.5	7.8	Y
31	Δ	1.9	2.2	3.6	5.0	7.2	Y
32	Δ	2.8	3.5	5.1	7.2	9.3	Y
33	Δ	4.0	5.2	7.4	9.2	12.2	Y
34	Δ	2.0	3.2	5.0	6.7	9.7	Y
35	Δ	1.8	2.9	4.4	5.7	7.9	Y

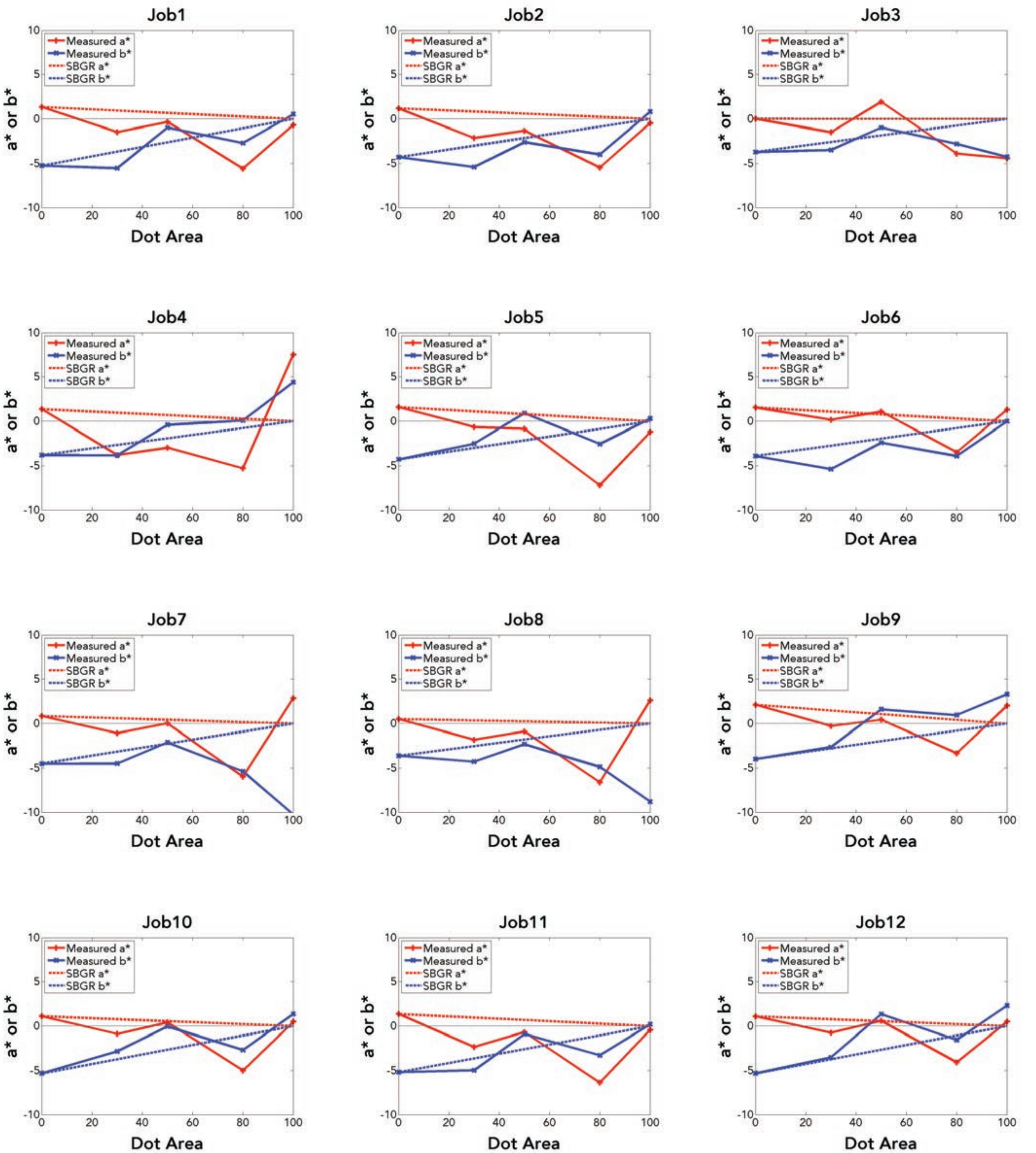
Magenta		90%	95%	98%	OK?
#	Tol.	3.0	1.5	-	
1	Δ	5.5	3.1	1.2	Y
2	Δ	5.2	1.7	0.4	Y
3	Δ	8.6	5.6	3.8	Y
4	Δ	8.7	3.1	1.1	Y
5	Δ	6.9	2.0	0.7	Y
6	Δ	4.2	1.3	0.9	N
7	Δ	15.9	8.2	4.5	Y
8	Δ	16.1	8.5	4.6	Y
9	Δ	8.7	3.6	1.7	Y
10	Δ	7.7	2.8	1.6	Y
11	Δ	5.4	3.2	1.5	Y
12	Δ	8.1	3.3	1.3	Y
13	Δ	7.4	1.2	0.5	N
14	Δ	9.4	5.1	3.7	Y
15	Δ	6.6	3.7	0.7	Y
16	Δ	9.7	5.2	2.0	Y
17	Δ	6.8	3.4	0.5	Y
18	Δ	13.4	6.3	4.0	Y
19	Δ	10.0	4.3	0.6	Y
20	Δ	9.4	4.6	0.9	Y
21	Δ	7.6	2.8	1.4	Y
22	Δ	7.3	2.3	0.9	Y
23	Δ	6.5	2.5	0.8	Y
24	Δ	5.5	0.7	0.4	N
25	Δ	6.0	1.1	0.3	N
26	Δ	8.4	1.1	0.5	N
27	Δ	9.5	1.5	0.7	Y
28	Δ	4.8	2.8	1.4	Y
29	Δ	7.9	3.7	2.0	Y
30	Δ	6.9	1.4	0.5	N
31	Δ	6.8	2.0	0.5	Y
32	Δ	4.7	2.4	0.6	Y
33	Δ	3.6	1.0	0.6	N
34	Δ	6.3	2.2	1.1	Y
35	Δ	6.6	3.5	1.8	Y

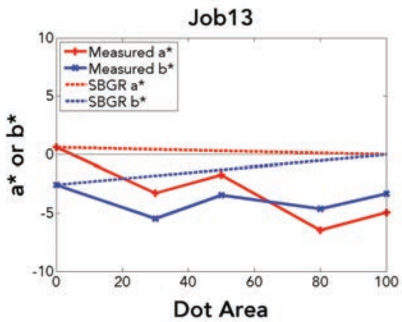
Appendix A: Job-Wise Conformance of Tone Reproduction Limits

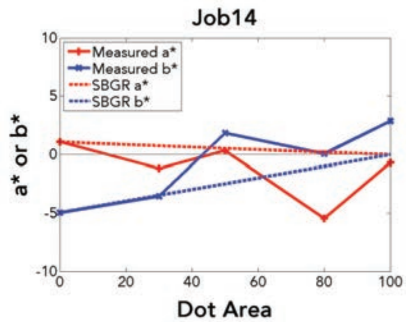
Yellow		2%	3%	5%	7%	10%	OK?
#	Tol.	-	-	3.0	4.2	6.0	
1	Δ	1.5	1.8	4.9	7.3	10.1	Y
2	Δ	1.8	2.2	4.0	5.5	8.4	Y
3	Δ	1.8	2.5	4.4	5.8	8.9	Y
4	Δ	3.2	4.0	6.0	7.9	11.2	Y
5	Δ	2.9	4.1	6.2	8.9	12.0	Y
6	Δ	2.0	2.8	5.1	6.8	9.5	Y
7	Δ	1.5	1.9	4.2	6.2	8.9	Y
8	Δ	1.4	2.1	4.1	6.0	8.7	Y
9	Δ	2.4	3.3	5.8	8.1	10.1	Y
10	Δ	3.5	4.8	7.8	11.5	14.4	Y
11	Δ	1.4	2.0	5.1	8.0	12.3	Y
12	Δ	3.4	4.2	7.5	10.7	13.6	Y
13	Δ	2.7	2.7	5.5	6.6	10.9	Y
14	Δ	1.3	1.8	3.2	4.7	7.0	Y
15	Δ	1.9	2.8	4.3	5.5	7.6	Y
16	Δ	3.3	3.4	5.6	7.3	8.1	Y
17	Δ	3.0	3.6	5.7	7.2	8.2	Y
18	Δ	2.1	2.4	4.7	6.2	8.7	Y
19	Δ	1.7	2.3	3.4	4.5	7.0	Y
20	Δ	1.6	2.1	3.2	4.3	6.7	Y
21	Δ	3.5	4.3	7.2	10.2	13.6	Y
22	Δ	2.9	3.8	5.5	7.0	10.2	Y
23	Δ	1.7	1.9	3.4	5.5	7.7	Y
24	Δ	2.6	3.3	5.1	6.3	8.4	Y
25	Δ	2.7	3.3	5.1	6.1	8.3	Y
26	Δ	3.1	3.1	5.2	7.3	9.5	Y
27	Δ	3.0	3.0	4.9	6.8	9.0	Y
28	Δ	1.1	1.7	3.9	6.4	8.6	Y
29	Δ	1.9	2.3	4.1	6.3	8.2	Y
30	Δ	1.8	2.7	4.6	6.1	8.4	Y
31	Δ	2.1	2.6	3.9	5.5	7.6	Y
32	Δ	3.0	3.7	5.2	7.0	9.7	Y
33	Δ	4.1	4.7	6.7	9.2	13.1	Y
34	Δ	1.7	2.3	4.5	6.5	9.3	Y
35	Δ	2.2	3.0	4.1	5.7	8.0	Y

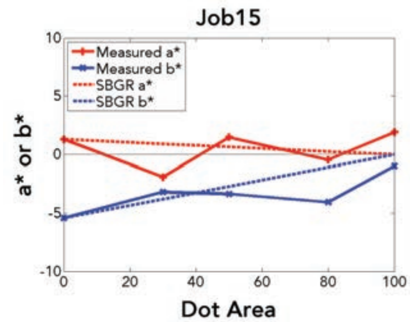
Yellow		90%	95%	98%	OK?
#	Tol.	3.0	1.5	-	
1	Δ	9.0	5.0	3.4	Y
2	Δ	7.3	3.2	0.4	Y
3	Δ	0.7	4.5	1.1	N
4	Δ	13.0	0.8	6.5	N
5	Δ	9.7	0.5	1.3	N
6	Δ	11.2	5.0	3.8	Y
7	Δ	8.7	0.8	4.2	N
8	Δ	8.5	0.7	3.1	N
9	Δ	10.6	5.3	0.4	Y
10	Δ	9.6	3.6	1.3	Y
11	Δ	8.3	4.4	3.0	Y
12	Δ	9.1	3.7	0.8	Y
13	Δ	4.4	4.5	1.2	Y
14	Δ	6.6	3.4	1.5	Y
15	Δ	2.3	5.1	2.1	N
16	Δ	14.7	6.9	1.9	Y
17	Δ	17.5	7.7	1.3	Y
18	Δ	11.9	6.6	1.0	Y
19	Δ	10.2	0.8	2.1	N
20	Δ	8.5	0.8	1.9	N
21	Δ	7.6	2.1	1.0	Y
22	Δ	7.6	4.2	4.6	Y
23	Δ	11.4	4.8	3.1	Y
24	Δ	11.9	0.8	1.5	N
25	Δ	9.7	0.4	1.7	N
26	Δ	7.5	1.7	1.0	Y
27	Δ	7.6	0.8	1.9	N
28	Δ	7.2	3.9	2.3	Y
29	Δ	7.0	4.6	1.1	Y
30	Δ	13.8	6.9	1.6	Y
31	Δ	7.4	2.4	0.7	Y
32	Δ	7.6	4.1	3.3	Y
33	Δ	7.6	3.5	1.6	Y
34	Δ	8.3	2.4	0.6	Y
35	Δ	12.0	2.8	2.1	Y

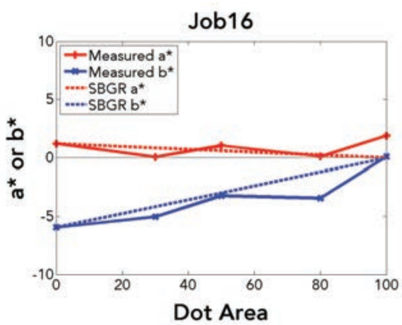
Appendix B. Grey Reproduction Curves and Their SBGR

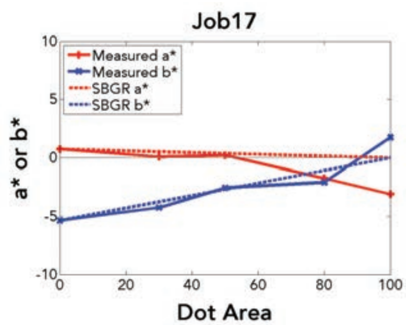


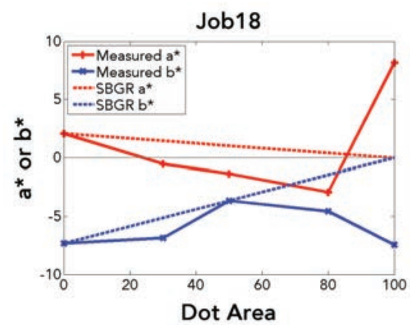

Job13
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

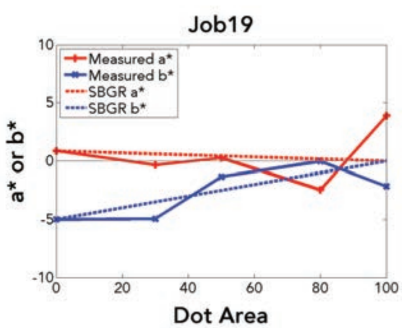

Job14
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

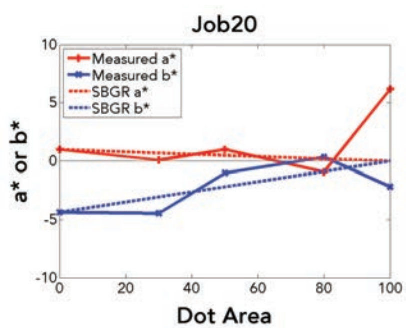

Job15
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

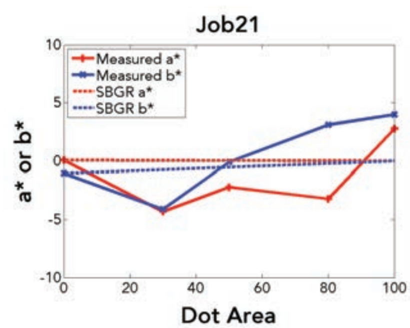

Job16
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

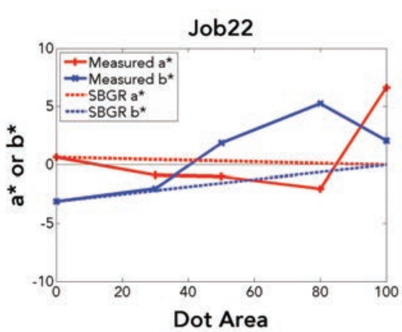

Job17
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

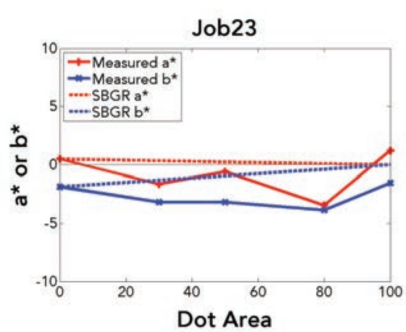

Job18
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

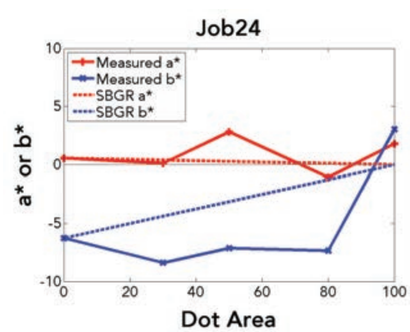

Job19
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

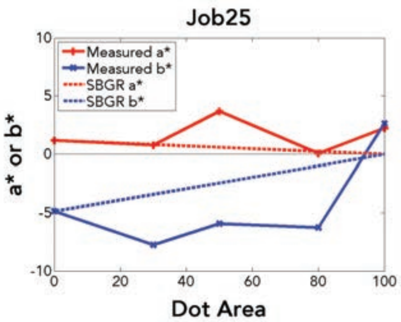

Job20
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

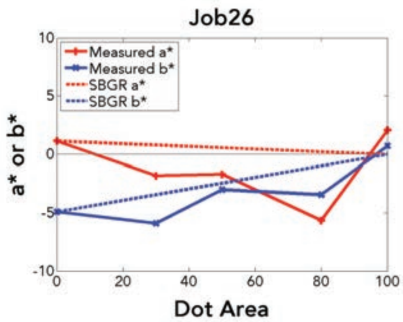

Job21
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

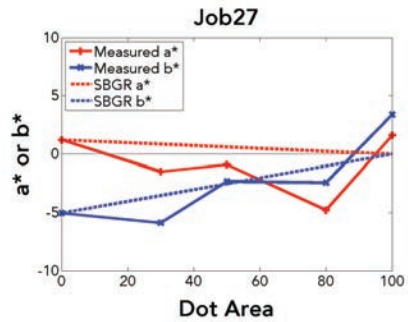

Job22
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

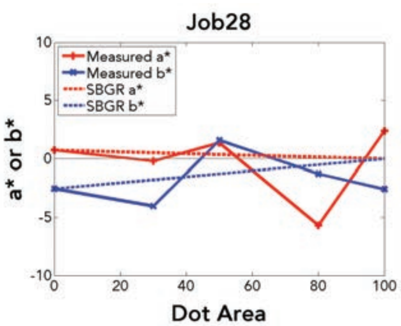

Job23
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

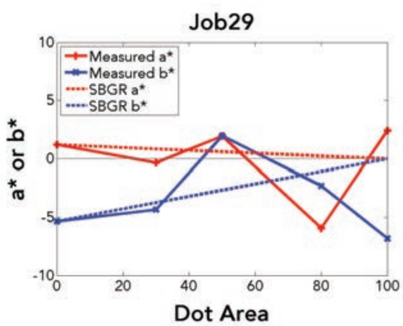

Job24
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

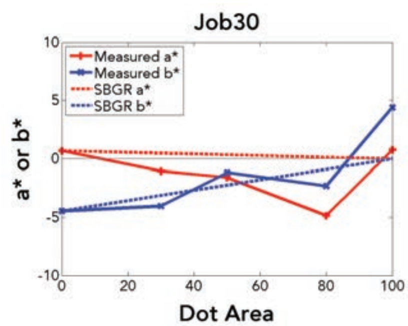

Job25
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

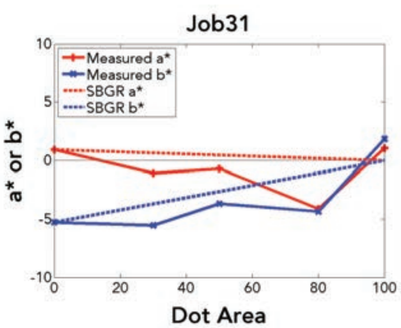

Job26
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

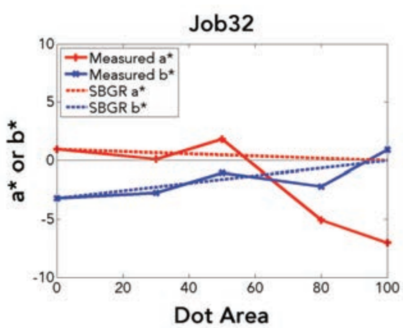

Job27
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

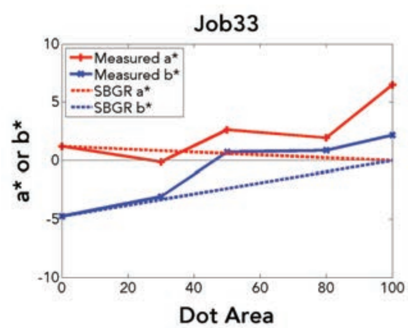

Job28
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

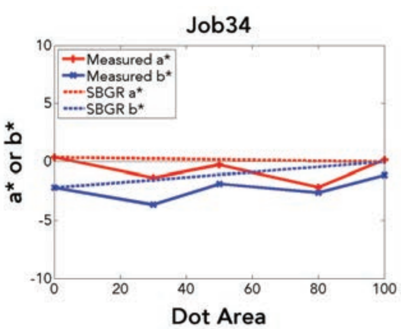

Job29
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

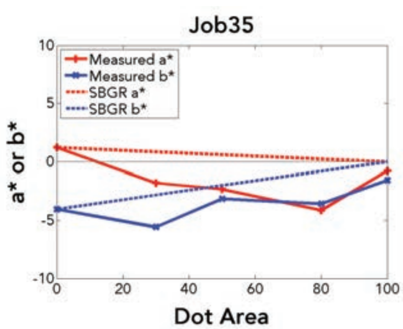

Job30
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area


Job31
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area


Job32
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area


Job33
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area


Job34
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area


Job35
Measured a*
Measured b*
SBGR a*
SBGR b*
a* or b*
Dot Area

Appendix C. Job-Wise Grey Reproduction Conformance

#	Tolerance	ΔL*_25	ΔL*_50	ΔL*_75	ΔC_h_25	ΔC_h_50	ΔC_h_75	OK?
		2.5	2.5	2.5	2.0	3.0	4.0	
1	Δ	1.1	0.4	0.1	1.5	2.4	2.1	Y
2	Δ	1.2	2.4	1.7	2.2	2.1	1.1	N
3	Δ	1.3	1.3	3.4	1.0	2.2	1.3	N
4	Δ	2.4	2.2	0.4	3.9	4.2	4.0	N
5	Δ	3.0	3.2	0.9	2.5	3.9	3.3	N
6	Δ	0.5	0.6	0.4	0.9	0.2	0.8	Y
7	Δ	0.8	3.7	5.2	0.9	0.7	1.8	N
8	Δ	1.1	3.5	5.4	1.2	1.2	2.2	N
9	Δ	0.8	0.7	1.4	2.1	4.0	4.8	N
10	Δ	0.6	0.4	0.7	2.9	3.1	1.9	N
11	Δ	0.1	0.1	1.3	2.5	2.7	2.3	N
12	Δ	0.7	0.0	0.3	2.2	4.5	3.0	N
13	Δ	0.8	1.2	0.1	3.4	3.0	2.3	N
14	Δ	4.5	3.4	1.5	2.1	4.8	4.5	N
15	Δ	2.2	1.3	2.4	3.2	0.6	4.0	N
16	Δ	2.5	2.9	1.9	1.1	0.4	4.7	N
17	Δ	2.3	2.6	0.7	1.5	0.7	3.8	N
18	Δ	1.5	0.0	1.5	1.2	2.8	1.5	Y
19	Δ	4.4	5.6	4.2	0.4	1.6	4.8	N
20	Δ	4.5	5.8	4.7	0.5	1.6	5.7	N
21	Δ	4.4	3.2	1.4	3.9	2.3	5.9	N
22	Δ	1.4	4.1	4.1	1.9	3.9	9.1	N
23	Δ	0.6	0.9	1.7	1.1	2.4	1.6	Y
24	Δ	1.1	2.9	0.2	2.1	4.2	4.4	N
25	Δ	1.5	2.7	0.2	2.6	4.2	4.9	N
26	Δ	0.4	0.7	1.4	1.8	2.4	1.4	Y
27	Δ	0.6	0.0	0.8	1.5	1.8	1.9	Y
28	Δ	1.3	0.4	3.2	0.6	3.1	2.2	N
29	Δ	0.7	2.9	3.8	1.4	5.3	2.6	N
30	Δ	2.5	3.3	1.2	1.1	2.5	1.8	N
31	Δ	1.8	1.0	1.6	0.8	1.4	0.5	Y
32	Δ	0.9	1.4	2.7	1.3	1.4	1.4	N
33	Δ	2.5	4.4	3.1	2.1	4.0	8.2	N
34	Δ	0.3	0.6	1.8	0.8	0.9	2.7	Y
35	Δ	2.3	2.5	2.4	2.0	3.2	0.4	N

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